USDA Forest Service
General Technical Report WO-3

Proceedings of the

Symposium on the Environmental Consequences of Fire and Fuel Management in Mediterranean Ecosystems

August 1-5, 1977
Palo Alto, California

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Issued November 1977

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Technical Coordinators

Forest Service
U.S. Department of Agriculture
Washington, D.C.

PREFACE

Regions of the world with a Mediterranean climate, such as South Africa, southern Australia, California, and countries around the Mediterranean Sea, are noted for frequent and devastating wildfires. The economic and environmental costs of these fires are tremendous. In 1970, for example, a single wildfire in California burned for 13 days, scorched more than a half-million acres, killed 16 people, destroyed 722 homes, and cost more than a quarter of a billion dollars in direct suppression costs and structural losses.

Approaches to controlling wildfires have varied. Some areas have no control policies. Others have management policies ranging from total fire exclusion to controlled burning to fuel manipulation. The environmental costs of these management possibilities have never been fully assessed. In those areas where a clear policy is evident, it may not be carried out because of social or fiscal constraints, or because of lack of information transfer between researchers and resource managers.

The need to develop an understanding of the full dynamics of fire-type ecosystems of Mediterranean regions is urgent so that management policies can be developed and assessed on a rational basis. Ways must be developed to facilitate communication between researchers and resource managers facing similar problems in different parts of the world. A system must be found to translate research findings into practical programs that can be transmitted quickly to resource managers and the public.

This Symposium, held at Stanford University, Palo Alto, California, on August 1-5, 1977, was designed as a step toward reaching such objectives. It was divided into six sessions covering (a) the nature of the world's Mediterranean ecosystems, (b) an assessment of man's interactions with those systems, (c) regional problems and approaches, (d) contributions to the study of Mediterranean ecosystems, (e) identifying research problems, and (f) a field trip to observe management practices in forests and scrublands of California.

The concern of the Symposium participants toward solving the wildfire problem promoted them to adopt unanimously the following resolution:

> Throughout Mediterranean-climate countries of the world, the peoples of different nations have problems in managing wildland vegetation to conserve and enhance their resources as well as to contain wildfires. Traditional programs focusing on fire suppression do not consider the relationship of fire to the environment.
>
> Research and practice have shown that wildland-fuels management can maintain and improve resources. In accordance with changing land-use patterns, such management should recognize all tools available, including prescribed fire. The public will benefit from wildland management on both public and private lands and should, therefore, share the costs and risks.
>
> This Symposium recommends that governments designate pilot areas to implement and demonstrate wildland-vegetation management programs as well as for the study and review of the role of fire in ecosystem and resource management.

To speed up the publication of Symposium Proceedings, we decided to have each author assume full responsibility for submitting manuscripts in photo-ready format by the time the conference convened. The views expressed in each paper are those of the author and not necessarily those of the sponsoring organizations. Trade names are used solely for necessary information and do not imply endorsement by the sponsoring organizations.

We gratefully acknowledge conference support from the following organizations:

- Man and the Biosphere Program of the U.S. Department of State and of the United Nations Educational, Scientific, and Cultural Organization.
- Forest Service, U.S. Department of Agriculture.
- National Park Service, U.S. Department of Interior.
- Jasper Ridge Biological Preserve, Stanford University.
- U.S. National Science Foundation.
- Scientific Committee on Problems of the Environment.

Many persons assisted in making the Symposium a success. In particular, we thank the workshop leaders: James Agee, A. Malcolm Gill, John W. Menke, Philip W. Rundel, and Carl. C. Wilson. Vincent Y. Dong and John K. McDonald of the Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture, Berkeley, California, handled the details necessary to the publication of these Proceedings. C. Eugene Conrad, also of the Pacific Southwest Station staff, organized the post-conference field trip. The manifold tasks of carrying out the Symposium were handled by Alan Grundmann, assisted by Arnold Bloom, Dorothy Comstock, Michele Grundmann, and William Williams—all of Stanford University

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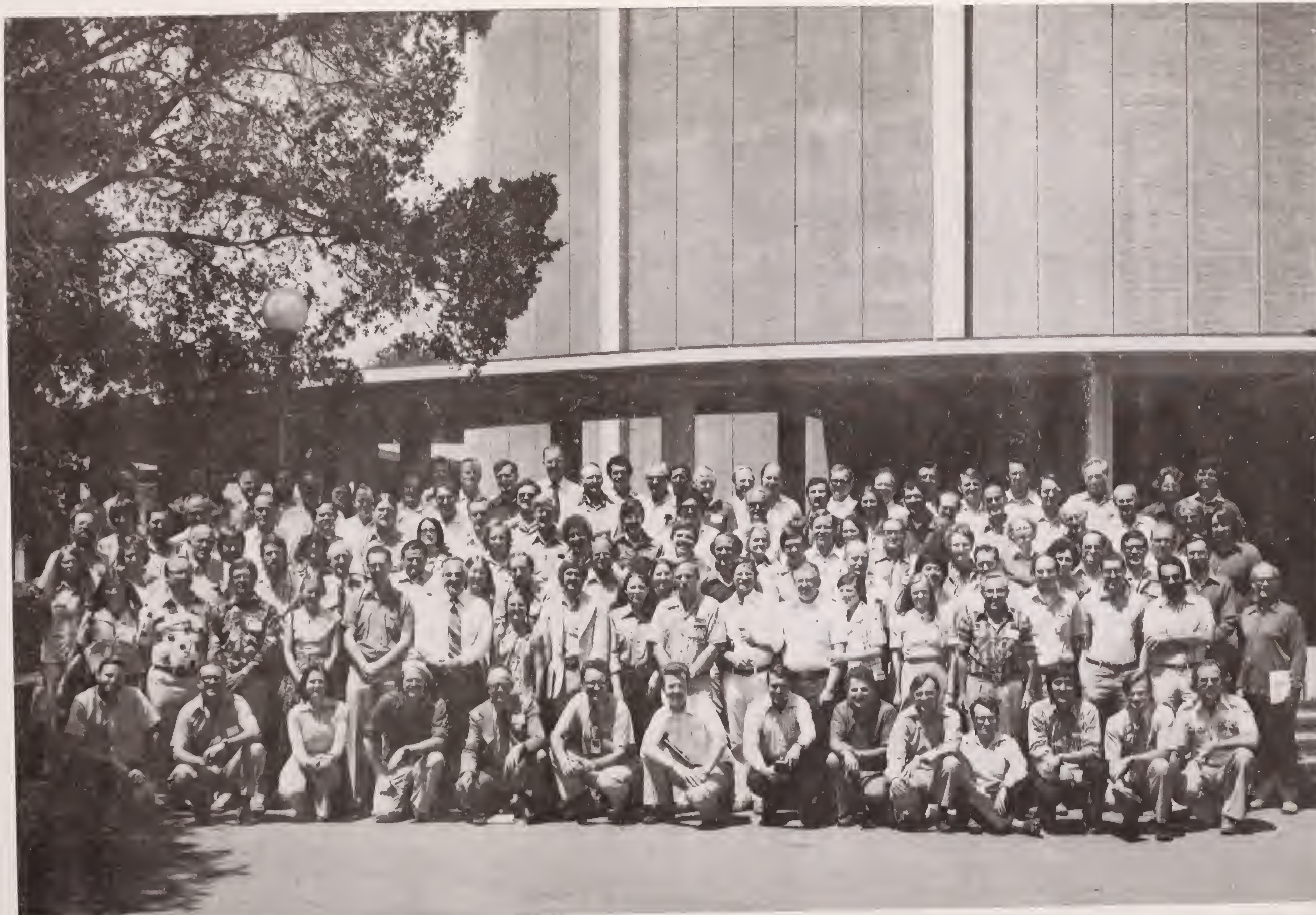

The Symposium on Environmental Consequences of Fire and Fuel Management in Mediterranean Ecosystems was held at Stanford University, Palo Alto, California, August 1-5, 1977.

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CLIMATIC FEATURES AS A FIRE DETERMINANT[1/]

Morris H. McCutchan[2/]

Abstract: High fire danger is associated with regions having a Mediterranean climate. A study of large fires and weather associated with them suggests the type of weather typically found during such fires. The study included measurements of mean dewpoints, mean maximum and minimum temperatures and mean precipitation for each month and their association with fire danger. A comparison of variations in climate shows both the general similarities from continent to continent and the differences within a few miles in the same general area. The significance of moisture in living and dead fuels as a fire determinant was also studied. The mean annual trends of live-fuel moisture content and fuel-stick moisture measurements on several National Forests in California show that warm, dry summers cause moisture content in both living and dead fuels to drop quickly.

Key words: Mediterranean climate; chaparral moisture content; Santa Ana winds; heat wave; forest fire.

INTRODUCTION

The Mediterranean climate has four important characteristics: (1) warm-to-hot summers and mild winters; (2) a moderate marine air influence throughout the year; (3) a concentration of the year's moderate amount of precipitation in winter and summers that are nearly or completely dry; and (4) extended periods of sunny weather and few clouds--especially in summer. This climate is found in the countries around the Mediterranean Sea, in Central Chile, Southwestern South Africa, Perth and Adelaide districts of Australia, and in the United States in most of California. On most days, the sea breeze blowing onshore produces a marine climate. Fires that start can usually be controlled when they are small. But if conditions are right, brush and forest fires can turn into disastrous conflagrations that ravage wide areas. These conditions include the Mediterranean climate, mountainous topography, highly flammable vegetation, heavy concentration of people, and heat waves from late spring to early fall and foehn or other strong desiccating offshore winds that replace the sea breeze in fall.

Severe heat waves accompanied by very low humidities that greatly increase the fire hazard are a prominent climatic feature from May to June and from September to October in North Africa, Israel, Lebanon, Syria, Turkey and Greece (Winstanley 1972). In Israel, heat waves are called Sharav (an old Hebrew term meaning "heat of the land"). Most wildfires of maqui in Israel occur on Sharav days (Naveh 1973). Across North Africa, dry, dust-laden winds called the Sirocco, or Khamsin, sweep eastward in advance of "desert depressions" that desiccate all life and create extreme fire danger (Winstanley 1972).

Heat waves in California that cause high fire danger occur when a subtropical High aloft persists over the Western United States, causing strong subsidence that in turn produces very high surface temperatures and low humidities (Schroeder and Buck 1970). For example, the 1974 Soboba Fire burned 6,545 hectares on the western slopes of the San Jacinto Mountains during a moderate heat wave.

[1/] Presented at the Symposium on Environmental Consequences of Fire and Fuel Management in Mediterranean Ecosystems, Palo Alto, Calif. Aug. 1-5, 1977.

[2/] Supervisory Research Meteorologist-Climatologist, Pacific Southwest Forest and Range Experiment Station, Berkeley, Calif., stationed in Riverside, Calif.

Most large fires in southern California occur when the marine airflow is replaced by the foehn-type winds called Santa Anas (Countryman 1974). During the Malibu fires of 1956, the Bel Air Fire in 1961, and the Coyote Fire of 1964, the Santa Ana winds surfaced and scoured the marine air out of the lee canyons, and the fires were carried downslope and into heavily populated areas where many expensive homes were destroyed (Fosberg and others 1966). The 1961 Harlow Fire in the foothills of California's Sierra Nevada that destroyed two small communities near Yosemite National Park burned during a few days of critical fire weather dominated by foehn-type Mono winds.[3/]

MEDITERRANEAN CLIMATE

Köppen (1931) defined the Mediterranean climate as subtropical dry-summer (Cs). The subtropics are transitional in climatic character between the tropics and the temperate middle latitudes. Temperature and annual precipitation are both important in defining subtropical dry-summer (Mediterranean) climate (Trewartha 1968).

The Mediterranean climate is found between 30° and 45° north and south of the equator and along the western edge of the continents. The water along these coasts is cold because of currents that flow equatorward and upwelling that brings cold water to the surface. In summer, the large subtropical high pressure cell tends to lie to the west of the coast and poleward, bringing dry subsiding air to the area. In winter, the cell tends to move equatorward and allows precipitation-producing fronts and cyclones of the westerlies to move through.

The climatic variables that best depict the "fire climate" of a particular location are monthly values of mean maximum and minimum temperatures, mean maximum and minimum relative humidities, and mean precipitation. These variables determine what vegetation will likely grow in a particular area, the moisture content of the vegetation, and depending on the particular combination of location, soils, topography, risk, and weather situations whether or not the vegetation is likely to burn.

The climatological data for this paper were taken from U.S. Naval Weather Service World-Wide Airfield Summaries,[4/] which did not contain mean maximum and minimum relative humidities but did contain mean dewpoint. In Mediterranean climates, diurnal variation of dewpoint is slight, particularly at the lower elevation stations. For example, diurnal variation of dewpoint at Madrid in January is 1.7°C, and at Los Angeles California in July, it is 0.5°C (table 1). Because of its small diurnal variation, the mean dewpoint can be used with the mean maximum and mean minimum temperatures to calculate with little error the mean minimum and maximum relative humidities. The mean relative humidity can be read from tables if available or calculated by this formula:

$$RH = 100 \exp\left[\frac{4157}{\overline{T} + 239.038} - \frac{4157}{\overline{T}_d + 239.038}\right] \quad (1)$$

in which $\overline{T}$ is the mean maximum or minimum temperature (°C), $\overline{T}_d$ is the mean dewpoint (°C), and RH is the relative humidity (percent).

Table 1--Mean dewpoint (°C) in the morning, early afternoon, and all day at three Mediterranean climate stations for January and July.

Month	06-08 LST	12-14 LST	All day
	Los Angeles, California		
January	2.7	4.4	4.5
July	15.0	15.5	15.1
	Madrid, Spain		
January	0.6	2.7	1.7
July	8.7	8.1	7.7
	Athens, Greece		
January	4.3	5.2	4.8
July	15.3	16.7	15.8

To depict the "fire climate" in the Mediterranean climate areas, climatic graphs which show mean maximum and mean minimum temperature, mean dewpoint and mean precipitation have been prepared for representative locations in the five regions of the world.

[3/] Wilson, C. C., 1977. Comparing forest fire problems in the Mediterranean region and in California. Special paper presented at FAO/UNESCO Technical Consultation on forest fires in the Mediterranean Region, St. Maximin, France.

[4/] Obtainable from National Technical Information Service (NTIS), Springfield, Virginia 22151.

The Mediterranean Sea Region

The climatic graphs for the representative stations in the Mediterranean area are given in figure 1. Cabo De Sao Vicente, Portugal is typical of stations located on cool water coasts. For example, in August Cabo De Sao Vicente has a mean maximum temperature of only 22°C, a range between the mean maximum and minimum temperature of only 5°C, and a mean dewpoint that closely follows the mean minimum temperature, indicating

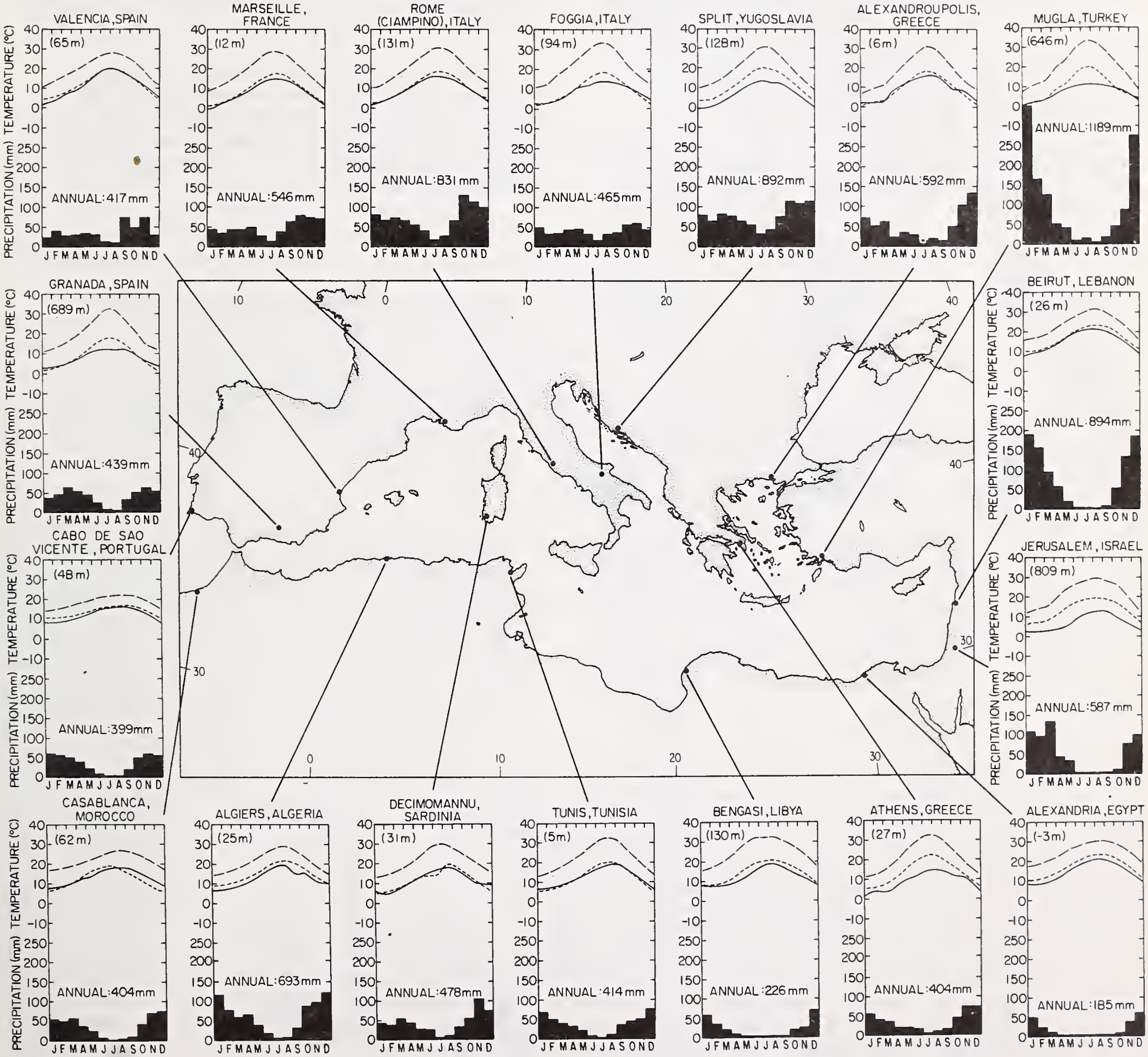

Figure 1--Climatic graphs for representative stations in the Mediterranean Sea region show mean maximum temperature (°C, large dashed line), mean minimum temperature (°C, small dashed line), mean dewpoint (°C, solid line), mean monthly and mean annual precipitation (mm). The elevation of the station is in parentheses in the upper left hand corner of graph.

quite high afternoon relative humidities and very high early morning humidity. Similarly, but to the south, Casablanca, Morocco in August has a mean maximum temperature of 27°C, a range between the mean maximum and minimum of 9°C, and afternoon mean relative humidities of about 50 percent.

In comparing the climates around the Mediterranean Sea, we find the maximum temperatures in August range from 28°C at Valencia, Spain on the coast to 33°C at the inland locations of Foggia, Italy and Mugla, Turkey. The difference between the mean maximum and mean minimum temperature in August is 15°C at Foggia, and only 7°C at Alexandria, Egypt on the coast. In August at Mugla the difference between the mean maximum temperature and the mean dewpoint is 23°C, indicating high temperatures and very dry air, while at Valencia the difference is only 8°C. Granada, Spain; Split, Yugoslavia; Athens, Greece; and Jerusalem, Israel along with Mugla are all inland stations except Split and they all show high temperatures and very low dewpoints during the afternoon in August.

In January all the stations in the Mediterranean region show cool daytime and chilly nighttime temperatures. Relative humidities at night are near 100 percent at all stations, except Split and Jerusalem, where a continental air influence is indicated.

Looking at precipitation we see most locations receive 400-600 mm annually. But those places on west coasts (Rome, Split, Mugla, and Beirut) all receive more than 800 mm. Alexandria has the minimum at 185 mm, Bengasi a close second at 225 mm.

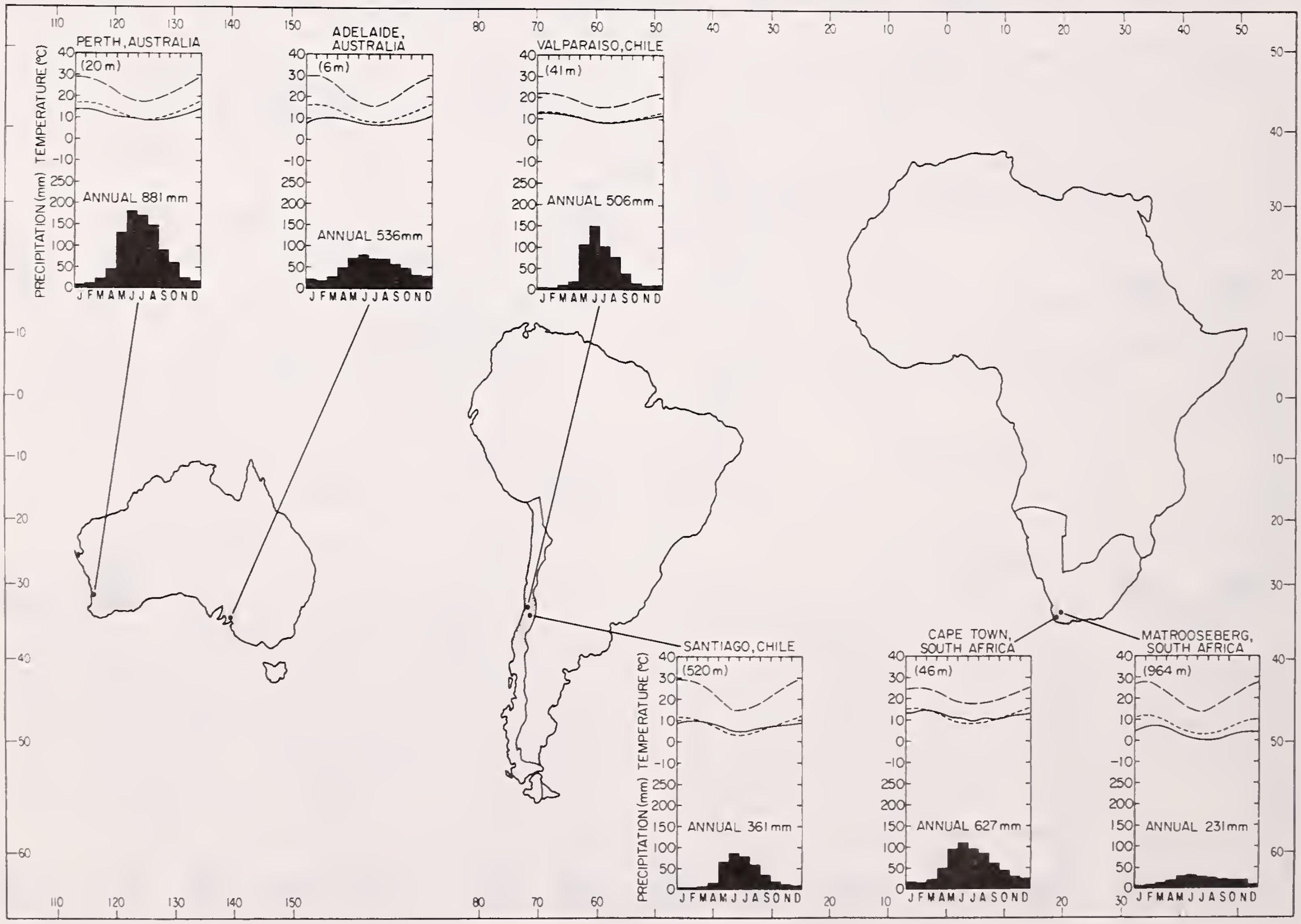

Figure 2--Climatic graphs for representative stations in Australia, Chile and South Africa show mean maximum temperature (°C, large dashed line), mean minimum temperature (°C, small dashed line), mean dewpoint (°C, solid line), mean monthly and mean annual precipitation (mm). The elevation of the station is in parentheses in the upper left hand corner of graph.

Australia, Chile, and South Africa

Perth and Adelaide, in Australia, have very similar mean maximum and mean minimum temperature patterns throughout the year (fig. 2). However, Adelaide is drier in January, differing by 21°C between the mean maximum temperature and the mean dewpoint, whereas the difference at Perth is only 15°C. Precipitation at Perth is 881 mm annually compared with 536 mm at Adelaide. This difference again demonstrates that west coast locations receive the brunt of the winter storms.

Valparaiso, Chile is on a cool-water coast, and its climate is almost identical to that of Cabo De Sao Vincente, Portugal. Santiago is an inland mountain station and this is reflected by a difference of 20°C between the mean maximum temperature and mean dewpoint in January. This difference results in an afternoon mean relative humidity near 25 percent.

The temperature and humidity patterns at Cape Town, South Africa are somewhat similar to those at Casablanca, but Cape Town receives 225 mm more precipitation. Matroosberg is an inland mountain station like Santiago and has a similar climate. Matroosberg is a bit drier both in relative humidity and in precipitation.

California

The Mediterranean climate of California is one of extremes (fig. 3). In August, the maximum temperature at Fresno, in the central valley, is 36°C, while at Eureka, on the cold-north coast, it is only 16°C. At Redding, the mean maximum temperature is 35°C and the mean dewpoint is 8°C in August resulting in a mean minimum relative humidity under 20 percent, whereas at Eureka the mean minimum relative humidity is 65 to 70 percent. The three northern stations (Eureka, Redding, and Quincy) have more than 1,000 mm mean precipitation and Lake Tahoe and Columbia in the Sierra Nevada have around 800 mm. In contrast, Fresno, in the central valley and Hemet, an inland station in southern California, have only about 250 mm. In summary, inland stations in California are quite hot, with mean maximum temperatures over 30°C, dry, with mean minimum relative humidities under 35 percent, and characterized by heavy precipitation in the northern and mountain stations and modest amounts of precipitation in the low elevation and southern stations.

Comparison of Fire Climates

Fire probabilities and burning indexes have been computed for each month at 24 key airfields around the Mediterranean Sea.[5/] The input was mean maximum and mean minimum temperatures, mean dewpoint, mean precipitation, annual mean maximum, and other data from U.S. Naval Weather Service World-Wide Airfield Summaries. Five locations have fire climates and fuels comparable with those of locations in California (table 2).

Table 2--Locations in the Mediterranean Sea region which have comparable fire climates and fuels to given locations in California.

Mediterranean Sea	Fuels	California
Valencia, Spain	Light to heavy brush	San Diego to Santa Barbara
Granada, Spain	Light to heavy brush	San Jose to Fresno
Decimomannu, Sardinia	Light to heavy brush	San Jose to Fresno
Foggia, Italy	Light to heavy brush	San Jose to Fresno
Athens, Greece	Light to heavy brush	San Jose to Fresno

FUEL MOISTURE

Living and dead fuel in the brush and forest areas have a built-in flammability potential. This potential is determined largely by the amount of water in the fuel. Fuel moisture is a continuous variable controlled by seasonal, daily, and immediate weather changes (Schroeder and Buck 1970).

Living Fuel Moisture Trends

The moisture content of living fuel is an important factor in fire behavior. Often it determines whether a fire will burn at all. Because of the current drought in California, land managers are especially concerned about actual fuel moisture measurements. For example, the California Department of Forestry is taking samples from 60 different areas throughout the State. The U. S. Forest Service's Forest Fire Laboratory at Riverside, California has been measuring live-fuel moisture and maintaining seasonal trends from fuel on established sites in four National Forests--two trends for 4 years and two for 12 years (fig. 4).

[5/] Chandler, C. C., 1976. Fire climates of the world. Unpublished manuscript on file in the Washington Office of the U.S. Forest Service.

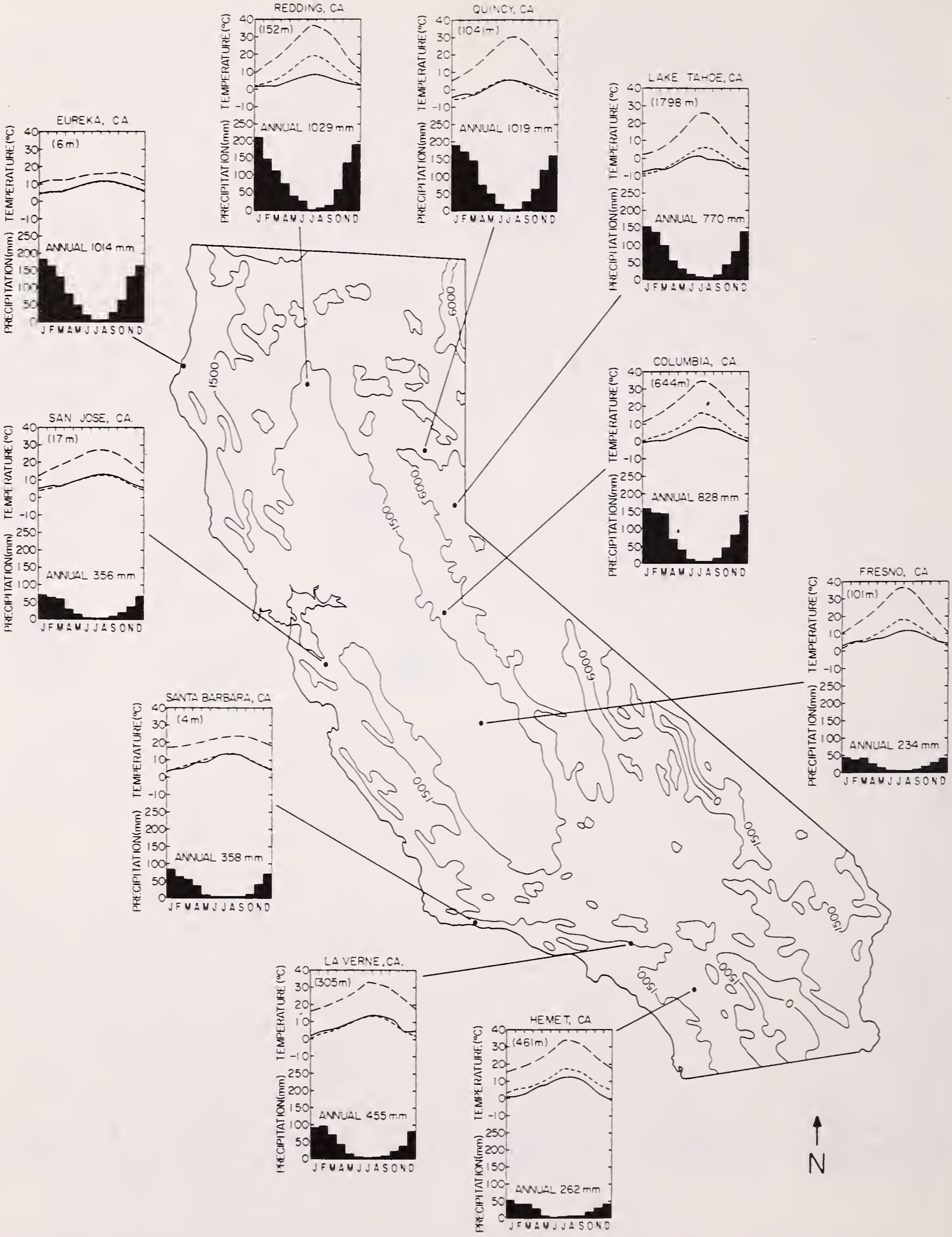

Figure 3--Climatic graphs for representative stations in California. Contours are in feet.

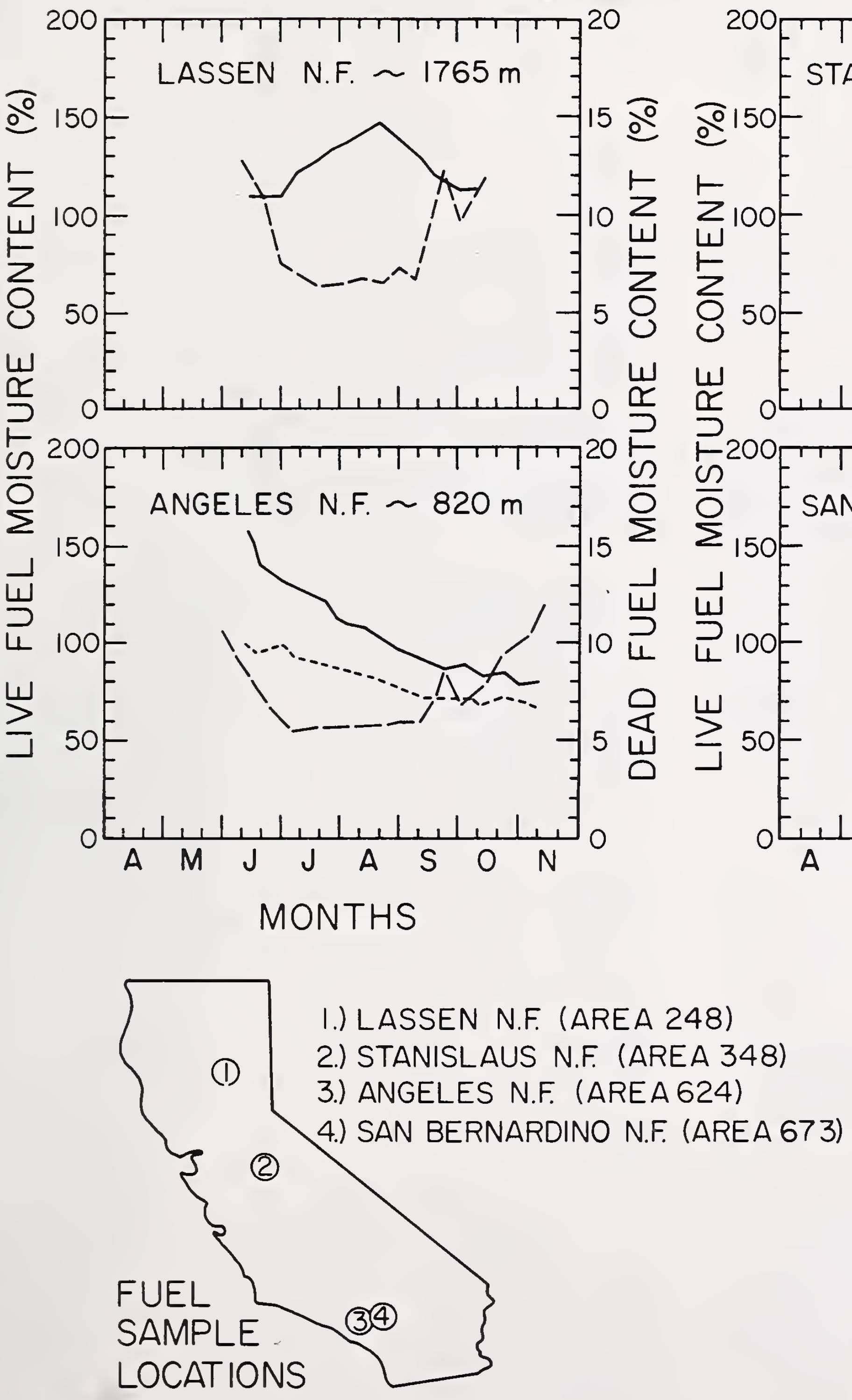

Figure 4--Live vegetation and fuel-stick (dead) moisture content for four National Forests in California: (a) Lassen and Stanislaus--live manzanita (%, solid line) and fuel stick (%, large dashed line); and (b) Angeles and San Bernardino--live (new growth) chamise (%, solid line), live (old growth) chamise (%, small dashed line) and fuel stick (%, large dashed line).

Live-fuel moisture of combined new- and old-growth greenleaf manzanita (*Arctostaphylos patula*) has been measured the last 4 years on the Lassen National Forest and 12 years on the Stanislaus National Forest. On the Lassen, the live-fuel moisture peaks at 145 percent in August with the emergence of the new growth and then decreases to 110 percent near the end of September when vegetation enters the dormant stage. However, the summer precipitation in the Lassen area has been greater than normal during the past 4 years, so the peak in August may be a bit later than normal. Nearby Quincy has a mean total of 10 mm of precipitation in July and August (fig. 3), but during the past 4 years it has averaged 35 mm for those 2 months. On the Stanislaus National Forest, the live-fuel moisture for the 12 years of record peaks at 155 percent in July and decreases to 110 percent at dormancy in late September. The fuel moisture trend fits the climatic graph for nearby Columbia (fig. 3).

New- and old-growth chamise (*Adenostoma fasciculatum*) have been measured separately for 12 years on the Angeles and 4 years on the San Bernardino National Forests. On the Angeles, the new growth peaks at 160 percent and decreases to 80 percent, while the old growth starts at 100 percent and decreases to 70 percent. La Verne is nearby, and lower in elevation, but the climate (fig. 3) corresponds quite closely with the live-fuel moisture trends at the Angeles site. Near Hemet (fig. 3) on the San Bernardino Forest, the new-growth fuel moisture peaks at 115 percent and then decreases to 70 percent at the dormant stage. The old growth starts at 80 percent and decreases to around 50 percent. These low readings reflect the hot, dry summers and the meager winter precipitation.

Dead Fuel Moisture Trends

If dead wildland fuels are dry, fires can start easily and spread rapidly. If the moisture content is high, however, the fuels are difficult to ignite and fires spread slowly (Countryman 1971).

Fuel moisture for fine fuels, such as cured grass and leaves, can be computed, except immediately after a rain, by using temperature, humidity, and state of the weather as variables. However, caution must be used because the relative humidity depends largely on the temperature. And the temperature at the fine fuel level can be very much higher or lower than those recorded in the instrument shelter.

In California, dead-fuel moisture of medium-size fuels is estimated by weighing "fuel moisture sticks." A set of sticks consist of four 1/2-inch ponderosa pine sapwood dowels connected by a 1/4-inch dowel. Each set is adjusted to weigh 100 grams when oven-dry. The sticks are exposed 0.25 m above a litter bed in the open. To record trends in dead-fuel moisture, fuel-stick moisture measurements (13 years of record) were averaged over the four fire danger rating areas in which the living-fuel moisture samples were taken on the four National Forests (fig. 4).

On the Lassen, the stick moisture showed 12.5 percent in early June, but decreased rapidly to 7 percent by July 1 and remained around 6 or 7 percent until the middle of September when it then rose sharply to 12 percent. The Stanislaus stick moisture was 11 percent early in June, dropped to around 5 percent during July and August, then climbed back up to 11 percent by the first of November. The fuel-stick trends for the Angeles and the San Bernardino are similar--each was 10 percent on June 1, dropped to 5 or 6 percent through July and August, then gradually rose to 10 percent again by November 1.

Combination of Living and Dead Fuels

On the Lassen, the living-fuel moisture started to rise as the stick moisture began to drop and by September when the living-fuel moisture started to drop the stick moisture began to rise (fig. 4). On the Stanislaus, the living-fuel moisture remained quite high through July and like the Lassen area the stick moisture rose as the living fuel moisture dropped. In the Angeles and San Bernardino areas, similar patterns of stick moisture changes occurred. In both areas stick moisture began to rise as the living plants reached their dormant stage. This can be misleading, however, because on heat wave days or Santa Ana days, both the living-fuel moisture and the stick moisture are reduced significantly. In an earlier study (McCutchan 1977), I classified each day during May-October 1973-1975 in southern California into one of five weather types: (1) Santa Ana days, (2) heat wave days, (3) hot and smoggy sea breeze days, (4) warm and smoggy sea breeze days, and (5) cool, cloudy, rainy days. The fuel-stick moisture trend at the Angeles site on days with either a heat wave or a Santa Ana condition was 2.5 to 3 percent lower than the mean fuel-stick moisture for all days combined (fig. 5). This lowering of the fuel-stick moisture, indicative of the lowering of dead-fuel moisture, combined with lowering living-fuel moisture and fine-fuel moisture on heat wave or Santa Ana days creates an extremely flammable fuel condition on such days.

FIRE WEATHER

The fire problem in some Mediterranean climate areas is usually confined to spring, summer, and fall. In winter, the westerlies drop down to these latitudes with fronts and low pressure centers and the accompanying rain and/or snow. In southern California, however, major fires in the winter are not unusual because the Santa Ana "season" extends from fall to early spring (Schroeder and others 1964). The Santa Ana periods increase in frequency in October and November, then decrease with a secondary maximum in March (table 3). During winter, the living fuels are dormant with low fuel moisture content (fig. 4), and the dead fuels can dry out rapidly during periods of Santa Ana activity. The Stewart Fire on the Cleveland National Forest in southern California burned 27,530 hectares from December 15-23, 1958. In March 1964 the Hume, Zuma, and Whiting Fires burned a total of 4,717 hectares, destroyed 20 houses and severely damaged 10 others in the mountains at the edge of Los Angeles. These are but a few examples of Santa Ana-caused fires.

Table 3--Frequency and duration of Santa Ana periods, by months, in southern California 1951-60.

Month	Frequency	Average duration (days)
September	11	4.4
October	19	4.5
November	26	5.0
December	18	3.7
January	7	1.7
February	10	1.9
March	17	2.5
April	8	1.8
May	7	1.4
June	4	4.5
July	2[1/]	2.5
August	0	0

Source: Schroeder and others 1964.

[1/]Affects only high elevation locations.

Large fires can occur in winter, but the Santa Ana periods that occur in September, October and early November before the rains come generally create the worst conflagration hazard. Both the living and dead fuel moisture are usually at their lowest levels (figs. 4 and 5), and the Santa Ana periods last an average of 4.4 days in September and 5 days in November. In 1970, between September 25 and October 4, during a very strong Santa Ana period in southern California, more than 202,430 hectares of brush and timber were burned. The loss of 16 lives was attributed to these fires, 700 homes were burned, and the fire damage and suppression costs have been estimated at $233 million (Countryman 1974).

The synoptic conditions most conducive for Santa Ana winds are a surface cold high pressure center in the Great Basin and a surface trough or low off the California coast (Serguis 1952). The surface weather map for 1200 GMT, September 25, 1970 (the first day of the disastrous fire period) shows a large high pressure center over the Great Basin and a trough off the California coast (fig. 6). The surface pressure at Los Angeles, California was 13.8 mb less than at Tonopah, Nevada, indicative of a very strong Santa Ana wind condition.

The Mistral, a strong, dry offshore wind that flows from the northwest, causes extreme fire hazard and many fires to the lower Rhone Valley and Cote d'Azur areas of southern France. The Mistral is defined in Marseilles as a wind with a lower limit of speed at 5 ms^{-1} and wind direction from 280° to 360° (Boyer and others 1970).

The Bora is another dangerous offshore wind that originates as a cold, continental outbreak of winter air from Russia that blows across Yugoslavia and over the Dalmatian Mountains and then down the steep slopes to the Adriatic Sea, arriving colder than the air it replaces (Defant 1951). The Bora is extraordinarily violent and often causes heavy damage and, of course, brings extreme fire danger to the Adriatic coasts of Yugoslavia and Italy. Most other Mediterranean climate areas are also affected by strong, dry, offshore, often downslope winds that replace the marine air and cause extreme fire danger.

The major fires during summer in California occur during heat wave episodes when a subtropical High aloft persists over the Western United States producing strong subsidence. The air, as it subsides, heats and dries out. In addition, the accompanying clear skies allow strong insolation to further heat the air and cause higher temperatures and corresponding very low relative humidities. Other examples of major fires breaking out under heat wave conditions besides the Soboba Fire, include the 1963 Dry Fire in the Angeles National Forest, which burned 5,263 hectares, and the 1964 Cozy Dell Fire on the San Bernardino National Forest, which burned 7,392 hectares. The southern and eastern Mediterranean Basin also has severe heat waves in May-June and September-October. Some of the highest temperatures recorded on earth occur during heat waves in this area.

Although the hot, dry weather in the Mediterranean climate areas is an important fire danger factor, the sea breeze is the dominant factor on most days. The sea breeze brings in a fresh surge of marine air that moderates the temperature and increases the moisture content of the air. The relative humidity is increased; in fact, at night the relative humidity can

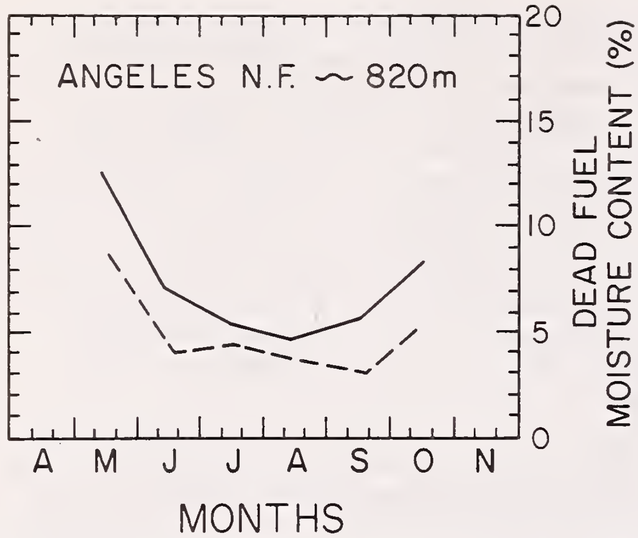

Figure 5--Fuel-stick (dead) moisture content for the Angeles National Forest in California for all days (solid line) and under heat wave and/or Santa Ana wind conditions (dashed line).

become extremely high. Under these conditions small fires can usually be controlled within a short time after they start (Countryman 1974). In southern California, the sea breeze transports marine air 80 miles inland to the San Bernardino Mountains where the marine air is then carried up the south-facing slopes to the crest of the mountain by the upslope flow (Edinger and others 1972). The sea breeze can be a menace or even prove disastrous when it interacts with or replaces foehn-type offshore wind flow during a fire. For example, in the 1968 Canyon Fire near Los Angeles, eight firefighters were fatally burned by a fire flareup when the sea breeze front moved into the area (Countryman and others 1969).

FRIDAY, SEPTEMBER 25, 1970

Figure 6--Surface weather map for 1200 GMT on September 25, 1970 shows large high pressure center in Great Basin and low pressure along the California coast illustrating a very strong Santa Ana wind condition in southern California.

CONCLUSION

The unique Mediterranean climate with its long, dry summer produces many days of great fire potential. The long, dry summer followed by periods of strong desiccating winds--especially in fall--creates conditions favorable for large, destructive, often disastrous brush and forest fires. Although the Mediterranean climates in California, Chile, Africa, Europe, and Australia are similar, they can differ significantly from one location to the next, mainly because of differences in distance from the coast and of changes of terrain. Significant differences in local weather occur from day to day because slight changes in synoptic conditions can cause air flow along the coast to vary from onshore to offshore and change the characteristics of the air over the coastal forests drastically. Consequently, the level of fire danger is also changed.

Measurements of live vegetation and moisture content of dead fuel sticks integrate the effects of weather and other variables on fuels. Thus, analyses of these daily measurements and annual trends provide a good understanding of how fuels react to normal annual weather cycles and how the fuels may vary under unusual weather situations. The examples described here show how fuel moisture content tends to drop in Mediterranean areas under the influence of the hot, dry summers. Changes in mean weather conditions are also reflected in fuel moisture trends.

Acknowledgment: I thank Dr. Bill C. Ryan, Clive M. Countryman, Lisle R. Green, Carl C. Wilson, and Bernadine A. Taylor for their consultation and suggestions.

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VEGETATIVE FEATURES AS DETERMINANTS OF FIRE FREQUENCY AND INTENSITY[1]

Charles W. Philpot[2]

Abstract: The vegetative characteristics of fuels and the climate directly affect the size and frequency of large fires in regions with the Mediterranean climate. These characteristics are inherited and interrelated with the adaptation to fire and drought. The inherent chemical, physical, and physiographic properties of the vegetation result in high-intensity, fast-spreading, large fires that have a higher probability of occurring as the vegetation becomes older.

Key words: fire intensity, fire behavior, fire occurrence, chaparral.

INTRODUCTION

Regions with Mediterranean climate have a history of large fires occurring consistently and behaving violently. Two basic reasons for this phenomenon are the type of fuels present and the climate. The previous paper in this Symposium explained some of the meteorological reasons for the fire history of these regions.

This paper describes the characteristics of vegetation that determine the frequency and intensity of large fires. These fuel characteristics are inherited and interrelated with the adaptation to fire and drought. Some forecasts of fire occurrences are offered, based on a study of the properties of California chaparral.

The chaparral of southern California is used here as a representative model to describe the characteristics and concepts relating to "fire-type" vegetation in Mediterranean regions. Many of my comments can easily be extrapolated, however, to other areas and species.

The chaparral of California is found from 500 to 3,000 feet in the north and from 1,000 to 5,000 feet in the south. Chaparral is made up of many species with chamise (*Adenostoma fasciculatum*) the most prevalent on many sites. Chaparral is active in winter and dormant in the summer and grows as even-aged stands of nearly continuous cover and constant height. Further descriptions of chaparral and related Mediterranean species will be covered in various papers during this Symposium.

THE MUTCH HYPOTHESIS

Mutch (1970) hypothesizes that vegetation that has developed in a fire environment and adapted to fire has inherent characteristics that make it flammable. Chaparral fits his hypothesis very well. In southern California, chaparral is associated with nearly 2 million years of fire history (Hanes 1971). The species making up this vegetative type have many unique adaptations to fire that insure continued occupation of a site after a fire. These species also have several inherent characteristics that make them more flammable with age.

Fire Cycle

The fire cycle, or autosuccessional cycle, for chamise can be used to demonstrate the dynamics of these processes. Currently, the cycle begins in a 20- to 30-year-old stand of chamise with a few other brush species and little or no understory. The fire sets the stage for autosuccession. Due to the destruction of phytochemicals, removal of the overstory, heat treatment of seeds and root crowns, or other fire effects, a whole conglomeration of "fire annuals" and grasses appear on the site. The root crowns of the brush species sprout and new brush plants are produced from heat-treated seed stored in the soil surface. After 2 to 5 years, the annuals disappear and

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the brush species begin to redominate the site thereby continuing the cycle. The flammability of the species insures its continuation as the dominant vegetation.

Vegetative Properties Controlling Flammability

The vegetative characteristics that control flammability can be classified as: chemical, physical, or physiological.

The two primary chemical characteristics related to flammability are inorganic mineral content and solvent extractables. Current evidence shows that the silica-free fraction of the mineral content influences burning rate (Philpot 1970). Plant materials with high mineral contents have low burning rates, lower available energy content, and higher char production. Plant material with lower mineral contents have the opposite characteristics. Chaparral species in general have lower silica-free mineral contents than other types of vegetation.

Solvent extractives influence burning rate because of their high heat content and availability at lower temperatures than the other plant constituents. A recent study investigating the role of extractives in determining the available heat content from chamise shows 3,410 cal/g with extractives and 2,230 cal/g without extractives (Chin and DeGroot 1975)*. This means 34 percent of the available heat content was due to the extractives. Chaparral species show some of the highest extractive contents; in fact, "fire-type" species as a group have a high extractive content. The vegetation of other Mediterranean regions also have a high proportion of resin, oil, and volatile products (Trabaud 1977).

The physical properties of chaparral that lead to high flammability include spatial continuity, branching habit, and size class distribution of the biomass. Continuous spatial continuity is a classic characteristic of chaparral. Many chaparral species have multiple stems emanating from a root crown or lignotuber. As a result, they have a high surface-area-to-volume ratio than single stemmed plants. The surface-area-to-volume ratio of chamise is a good example of this difference. Countryman and Philpot (1970) found that 65 percent of the volume and 61 percent of the weight of chamise were in material less than 1/2 inch diameter size class of biomass. This material represented 96 percent of the total plant surface area.

The physiological properties that influence flammability include moisture content and the seasonal and long-term dynamics of the chemical, physical, and physiological characteristics.

The moisture content of the living portions of chaparral species can drop severely during the dry season. Living fuel moistures of 50 percent dry weight basis are not uncommon. As the dry season progresses, the extractive content increases and moisture content decreases. In chamise, extractive content can vary from 8 percent in June to 13 percent in September (Philpot 1969). Both of these seasonal changes have a direct effect on how this fuel burns.

The other dynamic characteristic of chaparral that influences fire behavior is the tremendous increase in standing dead material with age. For example, by the time it is 30 years old, more than 50 percent of it may be dead (Philpot 1973). Also, as the stand ages, its height and mass increase. These changes, along with the other physical characteristics of this "ideal" fuelbed, insure increased flammability with age.

FIRE BEHAVIOR MODELS

The only effective way to assess all the characteristics of vegetation and their interrelationships is with mathematical models of fuels and fire behavior (Rothermel and Philpot 1973). The Rothermel model, which predicts spread rate and intensity based upon fuel, slope, and weather variables, is highly useful in chaparral fuels (Rothermel 1972). Output from the model can be used to show the changes in spread and intensity over season or with age based upon the corresponding changes in plant characteristics.

Examples of the model predictions are given in figures 1 and 2. Figure 1 shows the predicted effect of the seasonal changes in living chamise moisture and extractive content under constant weather conditions. For purposes of this analysis the windspeed was set at a constant 30 miles per hour, dead fuel moisture at 3 percent dry weight and average mortality and loading. The sustained rate of spread is predicted to soar from 36 to 200 feet per minute during the fire season for 30-year-old fuel.

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*Chin, P.S., and W. DeGroot. 1975. Heat release from forest fuels. Final report submitted to U.S. Forest Service, Northern Forest Fire Laboratory, Missoula, Montana, by Wood Chemistry Laboratory, University of Montana, Montana.

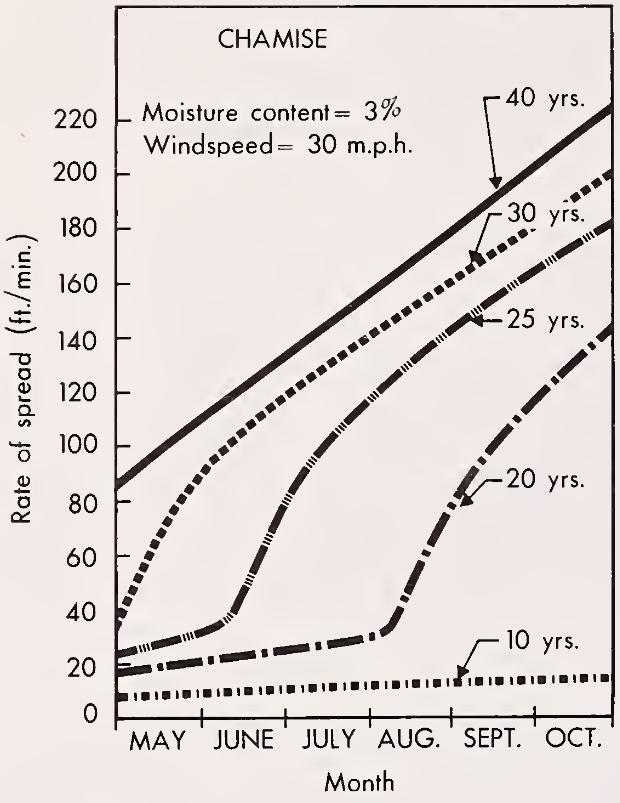

Figure 1--The predicted change in sustained rate of spread in chamise with season. The two variables which change with time are living vegetation moisture and extractive content.

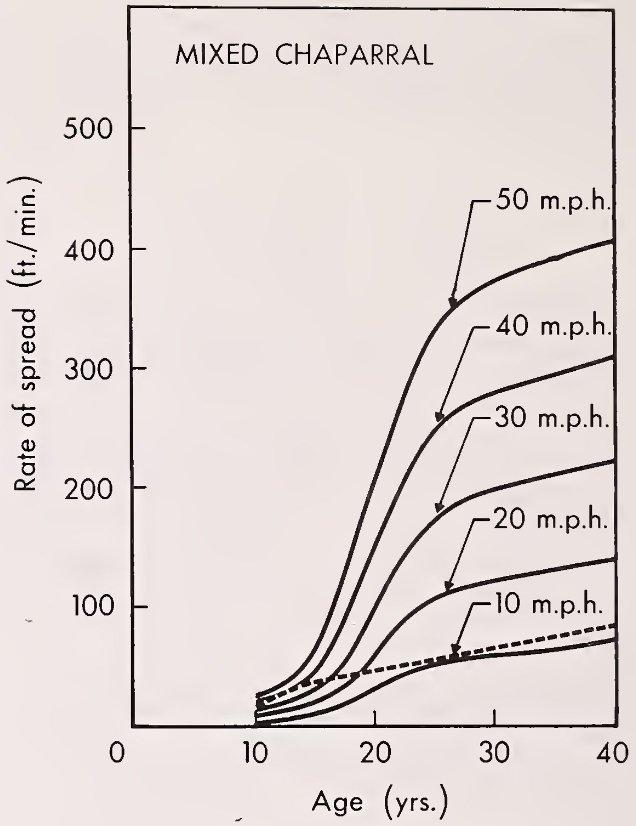

Figure 2--The predicted change in sustained rate of spread in mixed chaparral with age. The living moisture and extractive content are set for September 1.

Figure 2 shows the predicted change in rate of spread in mixed chaparral with change in age. Here again average dynamic loading and mortality functions were used and the dead fuel moisture was set at 5 percent dry weight basis. The shape of these curves and the spread caused by changes in windspeed clearly indicate the effects of age of vegetation on fire behavior.

FIRE FREQUENCY AND FIRE SIZE

The vegetative characteristics of Mediterranean fuels and the climate directly affect the size and frequency of large fires in these regions. The more recent fire history is also influenced by fire suppression technology. Since fire spread rate and intensity increase with the age of the vegetation, the probability of a large fire occurring is greater in old fuels than in young fuels because suppression success is higher when fire spread and intensity are lower. Total fire size is primarily controlled by the length of time severe wind conditions exist and the age of the fuel. Therefore, the large fires occur in older fuels.

The specific relationships between chaparral fire dynamics and management policy and actions have been previously covered (Philpot 1973). One of the most interesting exercises that can be done to further clarify this situation is to analyze the fire history on chaparral lands. If large fires of 100 acres or more are plotted by decades, it can easily be demonstrated that large fires do, almost without exception, occur in the older fuels (fig. 3). In fact, almost no large fires occur in fuels less than about 15 to 17 years on the San Bernardino and Angeles National Forests in southern California. Furthermore, many fires are successfully contained at age-class boundaries.

CONCLUSIONS

Chaparral and similar brush species in Mediterranean regions have developed and evolved in a fire climate. This has led to species with unique adaptations to fire and high flammability. The inherent chemical, physical, and physiological characteristics of these plants result in high intensity, fast spreading, large fires that have more probability of occurring as the vegetation gets

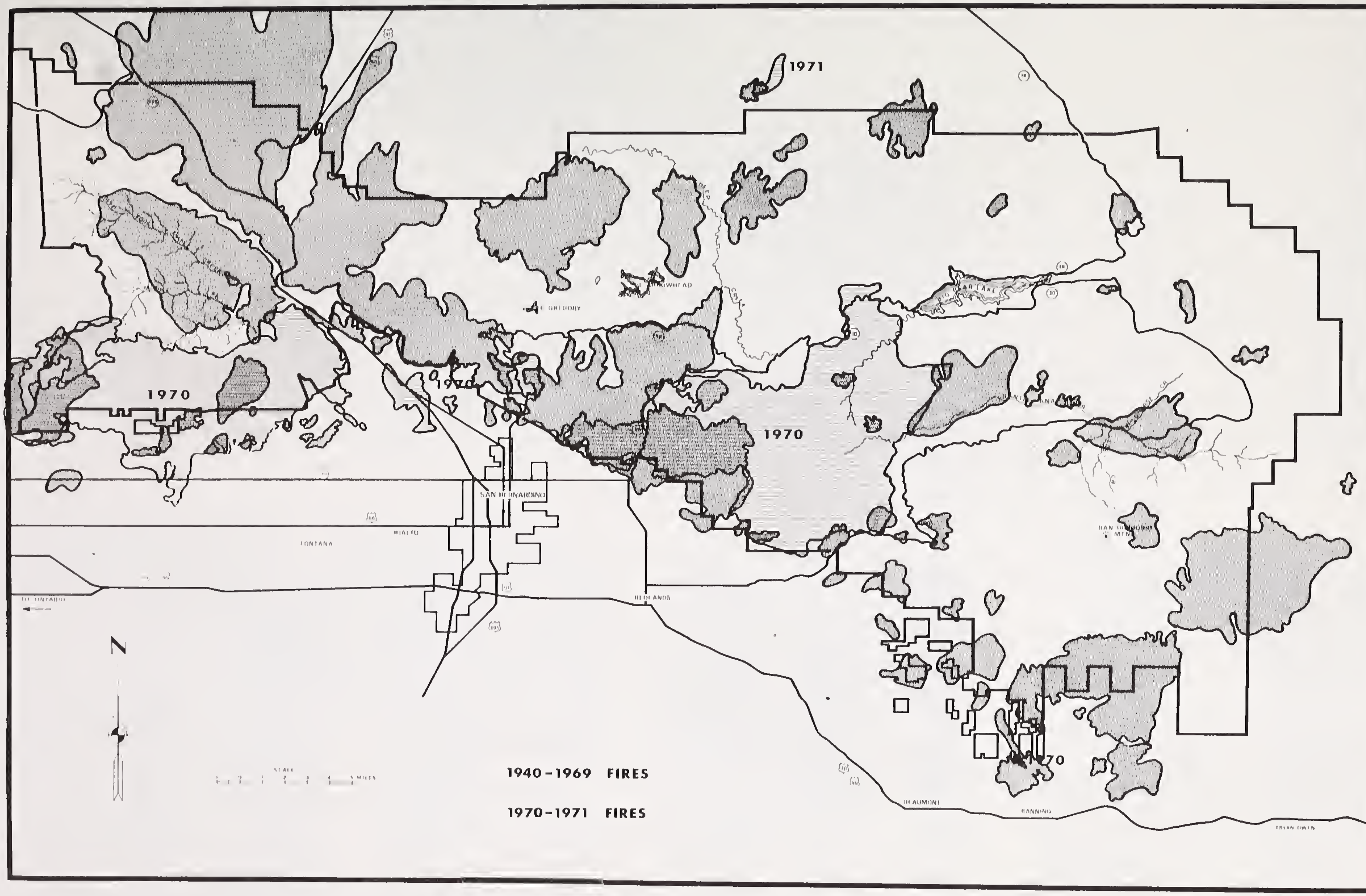

Figure 3--A map of the major portion of the San Bernardino National Forest and adjacent lands displaying the composite of large fire occurrence from 1940-1969. The 1970 fires, the two biggest in the history of the Forest, are also displayed.

older. Technology has provided us the ability to control and suppress all but the most violent fires that occur in the older fuels. Large fires may become larger because of the change in age class-mosaic size, and distribution. The solution to the problem lies in developing comprehensive land management plans that fully account for the unique characteristics and ecosystem dynamics of this vegetation.

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PLANT TRAITS ADAPTIVE TO FIRES IN MEDITERRANEAN LAND ECOSYSTEMS[1/]

A. Malcolm Gill[2/]

Abstract: For plants subject to fires the four major adaptive traits (i.e., those which enhance survival and/or reproduction) are: bud protection and sprouting; fire-induced flowering; on-plant seed storage and fire-stimulated dispersal; and in-soil seed storage and fire-stimulated germination. Some of these traits occur together in one species while others are mutually exclusive. The significance of these traits must be considered in relation to the life cycle of the species and the fire regimes of the area.

Key words: Adaptation, fire regime, life cycle, plant reproduction, plant survival, plant traits.

INTRODUCTION

The long warm and dry summers of Mediterranean lands provide ideal conditions for the development and spread of fires across the landscape - especially when dry and strong winds typical of many of these regions fan them. The plant communities fuelling these fires are often, but not always, dominated by woody plants. This contribution will concern the adaptations of these and associated plants to their fire environments. Not all the studies of relevant traits have been conducted in Mediterranean lands so some of the examples chosen for illustration in the text which follows, while applicable to plants in these regions, may have been carried out elsewhere.

What is an adaptive trait? Dobzhansky (1956) gave this answer: "An adaptive trait, then, is an aspect of the developmental pattern which facilitates the *survival* and/or *reproduction* of its carrier in a certain succession of environments" (my emphasis). Our concern, here, is with traits adaptive to fires. Because fires can occur at many stages of plant development - even in highly seasonal climates - adaptive traits may occur at a number of stages in the life cycle.

Vegetative *survival* of woody plants may vary at different stages of the life cycle according to the positions of any dormant buds and their protection by soil or bark. *Reproduction* may be enhanced by burning through the flowering response, through the release of seed held on the plant, or through fire-stimulated germination. Below, these plant traits, and the processes associated with them, are considered in turn. Australian examples are emphasized because of the author's familiarity with them, not because they are necessarily the most studied.

[1/]Presented at the Symposium on Environmental Consequences of Fire and Fuel Management in Mediterranean Ecosystems, Palo Alto, Calif. Aug. 1-5, 1977.

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VEGETATIVE SURVIVAL OF WOODY PLANTS

Survival of woody plants after fire depends on the survival of buds with vascular connections to the roots : if these buds survive but the foliage of the plant is killed then the buds form shoots, i.e., sprouting occurs.

Bud protection in *Eucalyptus*

The genus *Eucalyptus* (Myrtaceae), with its many hundreds of species, is perhaps the most frequent dominant throughout the Mediterranean lands of Australia where it grows in the form of trees or multi-stemmed shrubs (known as "mallees").

With the exception of perhaps 12-15 eucalypt species, all taxa have lignotubers (McArthur 1968). These woody growths begin as small structures in the axils of the cotyledons and first few leaves of the seedling (Chattaway 1958) in a similar way to the basal bud burls of *Betula* (Betulaceae) (Stone and Cornwall 1968). As the plant grows the lignotuber increases in size and becomes progressively buried in the soil. In tree species the prominence (and significance?) of the lignotuber may decline as the tree becomes larger. In mallee forms, however, where injury by fire is sometimes frequent, the lignotuber may increase in size continually. Of significance is the fact that the lignotuber is a source of living buds which may survive fire because of their subterranean position. The soil is not only a good insulator i.e. it has a low thermal diffusivity (Priestley 1959), but receives only a low proportion of the fire's heat also (Packham 1971): being buried is an effective protection from fire.

With buried lignotubers, the mallees are well endowed for survival in the event of fire. Eucalypts without lignotubers, however, such as the short *E. astringens* Maiden or the giant *E. diversicolor* F. Muell. must rely on protection by bark for survival. Older plants of lignotuberous tree species may also be dependent on bark protection if the lignotuber has become ineffective.

Like soil, bark is also an effective insulator. Thus the measurements of thermal diffusivity made by both Martin (1963) and Reifsnyder *et al.*, (1967) for North American trees are very low. The latter authors considered that the maximum possible variation in thermal diffusivity for the tree species they investigated was a twofold variation, but they concluded that variation in bark thickness was a more important variable in determining whether or not a tree was fire resistant.

Although bark thickness is an easy variable to measure there have been few *quantitative* studies of its significance in a fire context. Qualitatively, there has been wide acceptance of its importance to tree or organ survival in Mediterranean lands. Vines (1968) and Gill and Ashton (1968) studied its influence on temperature penetration for *E. obliqua* L'Herit., a species which extends into the Mediterranean lands of South Australia.

In *Eucalyptus* two extremes of bark type are, firstly, the smooth and moist "gum" type and, secondly, the loose, dry, fibrous "stringy bark" type (Chattaway 1953). Wallace (1966) notes that the latter may be a significant fuel factor in severe fires thus implying that bark thickness may decline during such fires.

The "gum" or smooth-barked eucalypts are particularly interesting in that heat-damaged bark is shed from the tree after the passage of fire. Not all of the bark in any one position on the tree need be lost: a new periderm is formed at the outer surface of the living tissue and the dead bark desiccates, cracks and falls off. In this way, bark thickness may be considerably reduced and the tree thus becomes more susceptible to a second fire. The recovery of bark thickness in the interim could be an important factor in survival. With incomplete bark loss, buds survive. If the foliage is killed the buds are released from correlative inhibition and develop into epicormic shoots.

The extent of bark loss from fire depends on the severity of the fire and the size of stem. Within the tree, bark loss also depends on height above ground and position around the bole. The latter occurs because the vortices created on the leeward side of the tree by the wind hold the fire against the tree: this phenomenon is influenced by tree diameter, wind speed and perhaps fire severity (Gill 1974, Tunstall *et al.* 1976). Such actions can cause superficial damage, death to one side only or complete bole death.

Bud Protection in Shrubs

Shrubs usually have thin bark and, if fire resistant, rely on the protection of subterranean buds from fire as afforded by soil. In the sclerophyll shrub vegetations of California and Chile, Mooney and Dunn (1972) found that almost 50% of the shrub species were "fire sprouters". Of all the flowering plants in Van der Merwe's

(1966) study in South Africa nearly 70% were regenerated from sprouts. Naveh (1974) found that almost all the common Mediterranean woody plants in Israel were resprouters. Protection of buds by soil and their outgrowth when crowns are damaged by fire is a very effective mechanism of survival. Regrowth can be rapid because of the availability of nutrients and carbohydrates in subterranean storage tissues.

The source of the subterranean regenerative buds may be important to population sizes after fire. If suckers are produced from a widely-spreading root system the size of the population after fire could exceed that prior to the fire. On the other hand, if regrowth occurs only from basal stem buds, plant numbers may remain constant - survival occurs but there would be no multiplication.

Many species of plants have abundant supplies of buds just below the soil surface in the form of lignotubers ("caudex" of Gardner 1957), e.g., in Western Australia they are found in some species of the Myrtaceae, Casuarinaceae, Proteaceae, Leguminosae, Tremandraceae, Sterculiaceae and Dilleniaceae (Gardner 1957). Some Epacridaceae also have lignotubers while in the Northern Hemisphere, Ericaceae also provides examples such as *Arctostaphylos* (Jepson 1916).

While bud protection and sprouting after fire is often an effective survival mechanism the extent of survival may depend on the vitality of the plants prior to burning, and the severity of the fire (Naveh 1974). Aged plants seem less able to survive than younger mature plants (Kayll and Gimingham 1965) while vitality may also be influenced by season of burn (Doman 1968, for California shrublands). That repeated burning of sprouting plants lowers their vitality has been shown for understory hardwoods in southeastern U.S.A. where repeated annual burning eliminated sprouting on 85% of rootstocks and biennial summer burning eliminated sprouting on 59% (Grano 1970).

Bud Survival and Sprouting as an Adaptive Trait

Sprouting is subject to correlative inhibition within the plant and is enabled by the death or removal of inhibitory organs such as leaves, irrespective of the agency of removal. Thus leaf removal by browsing, disease, insects or drought may be just as effective as fire in sprout inducement. Axelrod (1975) suggests that crown sprouting is probably an ancient trait among angiosperms because it is widespread in taxa of diverse origin and habitat. It may be seen as an adaptive trait to fires (subject to limitations of plant vitality) because it aids survival. However, sprouting did not necessarily arise as a direct response to selection by fire. A parallel may be drawn with shrubs which sprout when exposed to a *new* selective agent viz, α radiation (Woodwell 1967) : the shrubs are "adapted" to the radiation because of their survival, even though they had never been exposed to it previously. Thus, sprouting may best be considered as an adaptation to stress, one of these stresses being fire occurrence.

FLOWERING AND FIRES

The passage of fire may stimulate resistant plants to produce inflorescences : this has been observed particularly in geophytic orchids and studied particularly in Xanthorrhoea australis *R. Br.*

Xanthorrhoea australis, an Australian endemic

Xanthorrhoea occurs in Australia's Mediterranean-climate regions but is also widespread in Eastern Australia. "*X. australis*" of Specht *et al.*, 1958, (considered to be *X. semiplana* F.v.M. by some authors, e.g., Coaldrake 1951) is an important element of heathland floras in South Australia but the studies described below have been conducted in the Australian Capital Territory. Initial studies carried out by Gill and Ingwersen (1976) have been continued by Gill (unpublished).

X. australis is a thick-stemmed sparsely-branched plant up to about 2.5 m tall. The stems are well protected from fires by a densely-packed mass of persistent leaf bases. The long needle-like leaves produced in the crown apparently live about 2-3 years, reflex downwards against the stem and accumulate as a dry thatch. Upon ignition the dry thatch burns well, especially if fanned by a breeze.

Initial experiments were conducted by burning and clipping individual plants in spring. Among the burned plants, 87% produced inflorescences 4-7 months after treatment. Plants whose leaves were removed by cutting showed a similar response. Of the 30 control plants 37% produced inflorescences 7-10 months after the beginning of the experiment, an unusually high frequency.

Unpublished work suggests that season of burning has a very important role in affecting inflorescence initiation and reproductive potential. Six months after the last fire and last defoliation by cutting in an experiment

designed to investigate the importance of seasonal effects, the spring and summer treatments had produced abundant inflorescences while the autumn and winter treatments had produced relatively few inflorescences. Control plants responded by inflorescence production in fewer than 5% plants.

After initiation of inflorescences losses may subsequently occur from a specific inflorescence predator of *Xanthorrhoea* - the larvae of the moth *Hylaletis latro* Zeller (Dr. I.F.B. Common, personal communication). Seed production is influenced by these tunneling larvae, but also by the prevalence of pollinators at flowering and the depredations of birds (e.g. the yellow-tailed black cockatoo, *Calyptorhynchus funereus* Shaw) seeking larvae in the inflorescences.

Geophytes and other plants

The flowering of plants like *Xanthorrhoea australis* immediately after burning, and its virtual absence beforehand, is an extreme example of this type of adaptive trait. However, the habit also occurs in a number of fire-resistant plants, especially geophytes. In Australia, the orchids *Lyperanthus nigricans* R. Br. and *Caladenia menziesii* R. Br. provide examples (Willis 1962). In Israel, flowering geophytes increase rapidly after fire (Naveh 1974) suggesting increased flowering or vegetative reproduction. In South Africa, "fire lilies" such as *Haemanthus canaliculatus* Levyns flower more abundantly after fire (Levyns 1966) as do a number of "fire herbs" e.g. *Cyrtanthus contractus* N.E. Br., family Amaryllidaceae (Martin 1966) and orchids e.g. *Orthopenthae bivalvata* (L.f.) Rolfe (Hall 1959). Muller *et al.* (1968) give a number of Californian examples - *Brodiaea pulchella* (Salisb.) Greene (Amaryllidaceae), *Zygadenus fremontii* Torr. (Liliaceae), *Chlorogalum pomeridianum* (Dr.) Knuth. (Liliaceae), and *Calochortus* spp. (Liliaceae).

The reasons for these fire responses remain unclear. Martin (1966) suggests that changes in the diurnal range of temperatures following fires may act as a stimulus; reduction in competition is also a possibility. Naveh (1974) indicated a role for increased light intensity for the flowering response but calls for a thorough study of the phenomenon.

The above examples have come from perennial fire-resistant species. Behaviour of some annuals and biennials will be described later when seed germination is considered.

Significance of the Flowering Response

Flowering responses to fire would seem to have arisen by direct selection for increased seed production but the significance of the trait could be related to various environmental pressures. For example, increased flowering and seed production after fire could allow use of a "prepared" seedbed and thus enhance establishment; alternatively, cyclic flowering stimulated by the passage of fire could prevent the build up of populations of specific predators to inflorescences (e.g. in *X. australis*) and thus allow successful reproduction to occur. Alternatively, pollination of geophytes could be favoured by shrub removal and increased light.

ON-PLANT SEED STORAGE AND FIRE-STIMULATED DISPERSAL

"The primary adaptive functions of fruit morphology, chemistry and behaviour are seed protection and dispersal to safe sites" (Janzen 1971).

Banksia ornata F. Muell.

Annual seed release from perennial plants is disadvantageous for reproduction if seedling establishment is unsuccessful. If, however, seed release coincides with the provision of highly suitable seedbeds then reproduction is assured : such is the case for many species with dehiscent woody fruits which release their seed soon after fire. An example of this is *Banksia ornata* (Proteaceae) a shrub often dominant in heaths of southeastern South Australia and western Victoria (Black 1963, Sibley 1967).

The woody follicles of this species first form when the plant is about 5-7 years old (Specht *et al.* 1958, fig. 1). Gill (1976) found that about 1% of those follicles on intact mature plants had ruptured; the proportion was substantially higher on dead limbs. From mature stands after fire there is massive seed shed and seedling establishment (Specht *et al.*, 1958, fig. 1). If stands have not reached reproductive maturity, however, the passage of fire may eliminate the species from the area.

While a fire's heat is required to open most of the follicles on living plants of *B. ornata*, the closely-related *B. marginata* Cav. (which can occur in the same plant community) has woody fruits which open without heat and which do not store seeds. In other genera such as *Hakea* (Proteaceae) seed retention in woody follicles may be common but release occurs upon death of parent branches: such death is usually associated with fire. In *Eucalyptus*, some seed may be shed each year but upon death of the crown two or more years

seed may be shed : storage is partial rather than complete and dehiscence, triggered by shoot death, may depend on fire severity and scorch height.

Many genera of Australian Mediterranean lands exhibit seed storage on the plant. Examples given by Gardner (1957) for southwestern Western Australia come from the families Cupressaceae, Casuarinaceae, Proteaceae and Myrtaceae.

Pinaceae

A number of *Pinus* species have cones which are mainly dehiscent after fire, the so-called "serotinous cones". Mediterranean-region examples are *P. halepensis* Mill. and *P. brutia* Ten. (Naveh 1975). A North American example, for which much is known is *P. contorta* Dougl. In the cones of these species the bracts are held by a high-temperature resin which melts during the passage of fire thus enabling the seeds to fall (e.g. Lotan 1975).

P. contorta is a particularly interesting example because its cones vary from serotinous to freely dehiscing. In more frequently burned forests of *P. contorta* cone serotiny was common but in the less-frequently burned stands where Douglas fir (*Pseudotsuga menziesii* (Mirb.) Franco) was dominant, *P. contorta* was freely dehiscing (Smith 1970). Where *P. contorta* had regenerated over extensive periods without fire, serotiny was uncommon but in fire-regenerated forests the condition was predominant (Lotan 1967). Recently, Lotan (1975) considered that young trees could have open cones, old overmature trees could have partial serotiny and mature trees older than 20-30 years had increasing serotiny.

Significance of the Dry Fire-dehiscent Fruit

Seed falling from fire-released fruits falls onto a pyrogenic seedbed enhanced nutritionally by ash and heat, enhanced competitively by reduced water use of some or all competitors and usually well lit through removal of shade. How much seed is shed is important and this quantity is influenced by a number of variables : the age of first seed production, yearly fruit set, seeds per fruit, extent of predation, and seed longevity.

If fires occur very frequently, production of seed in early years is important. *Pinus contorta* may produce seeds when only a few years old (Smith 1970); mallee eucalypts may produce seeds on vegetatively regenerating plants 2-3 years after fire (Gardner 1956); *Banksia ornata* may take 5-7 years from seed (Specht *et al.*, 1958, fig. 1). If fires are infrequent, however, investment in vegetative growth rather than reproductive growth may be beneficial.

For an effective seed fall after fire the seeds must be well protected from heat during the fire, and from predators and disease during the interfire period. The fruits need to be exposed to fire for dehiscence, however. Thick walls of woody fruits may deter insect predators and provide effective insulation; low moisture content may deter fungal attack.

IN-SOIL SEED STORAGE AND FIRE-STIMULATED GERMINATION

Constraints on seed germination, which allow accumulations of viable seed in soil, may be relieved by fire.

Soil-seed banks

Remarkable germinations of seeds in recently burned plant communities can usually be attributed to the shedding of seed from on-plant storages (as discussed above) or the germination of seed stored for a number of years in the soil. In a few cases the migration of seed into the area from unburned sources may also play a role. The release of soil-stored seed by fire, allowing it to germinate, has been attributed to two main causes viz. release from hard seededness or allelopathy. Because reproduction is enhanced by both mechanisms and is due to the occurrence of fire we may designate the plant properties involved as adaptive traits. The two mechanisms involved are discussed separately below.

Hardseededness

This property is best known for plants of the family Leguminosae (e.g. Martin *et al.* 1975) but is found in a wide variety of families including Anacardiaceae, Compositae, Gramineae, Malvaceae and Proteaceae (see Ballard 1973) : it is not confined to woody plants (Ballard *loc. cit.*) and is found to be a property of seeds from a variety of fruit types. The property is typified by lack of imbibition, swelling, and softening when exposed to water. Seeds germinate promptly when the seed coat is removed however (Ballard 1973). No studies of the processes of release from this type of dormancy seem to have been made in a fire-effects context but the principles which are being established in

other contexts (mainly agricultural) may enhance our understanding of seed behaviour in fire-prone environments.

Hardseededness becomes apparent as seeds dry out (Quinlivan 1968): at higher seed moisture contents water absorption by the testa was possible but below a critical lower moisture content impermeability occurred.

Release of seeds from impermeability has been linked to changes in the strophiolar area for legumes especially at non-fire temperatures. Quinlivan (1968) showed that softening of seeds occurred under diurnal temperature fluctuations and that this was associated with fracture of the seed coat at the strophiole. Recently, Ballard *et al.* (1976) found that strophiole permeability increased as seed temperature increased to about 80°C when germinability began to decline. However, above about 130°C softening could be attributed to seed-coat cracking or charring.

The results of Floyd (1966) for the germination of seeds found in eastern Australian forests show that responses to temperature depend on the duration of exposure. Long periods of exposure to relatively low temperatures can give the same response as short exposures at high temperatures irrespective of whether or not the response was germination or death. In the field, then, the response of the soil-seed bank will depend not only on the properties of the seed but also on the properties of the fire, viz., its effect on soil temperatures and their duration. Christensen and Kimber's (1975) field data show this.

Allelopathic Inhibition and Fire Release of Herb Seeds

In the California chaparral abundant germination and flowering of numerous herbaceous annuals and biennials occurs after fire but these species disappear within a year or two (Muller *et al.* 1968). In South Australian heath Specht *et al.* (1958) noted a similar but less widespread behaviour in *Helichrysum* spp. (Compositae) and *Stipa* sp. (Gramineae). Similar responses are apparent in Israel (Naveh 1974) and in South Africa (Adamson 1935). This type of phenomenon has been investigated by Muller *et al.* (1968) who concluded that the flushes of herb growth and flowering after fire in California were due to the release of soil-stored seed from a chemical inhibition imposed by the shrub canopy. However, in view of the hardseededness of many plants from many families (Ballard 1973) sweeping generalizations attributing germination responses to allelopathy in uninvestigated cases is unwarranted. Such caution need not detract from the firm case built up in California for chemical control of seed germination and its release by fire.

In the investigations of Muller *et al.* (1968) in California field observation of the occurrences (or lack of them) of seedlings suggested that light, moisture and mineral nutrition were not limiting germination. However, extracts of shrubs did affect germination of fresh seeds. Other observations were made on the behaviour of seeds in the soil : germination of soil seed was enhanced by heating for an hour at temperatures up to 80°C; germination was also enhanced by clearing away the shrub canopy. The authors concluded that heat is not necessary for germination but may stimulate it. Furthermore, fire removes the source of a very labile germination inhibitor. As shrubs re-establish, seed inhibition resumes but the seeds remain viable until a further fire occurs.

Soil Seed Banks and Their Significance

As with the on-plant storage of seed, the size and persistence of the seed bank in the soil will depend on rates of accessions and losses. Accessions to the seed bank may be governed by many factors. Immediate post-dispersal seed predation may perhaps be minimized by myrmecochory (which is very widespread in Mediterranean lands of Australia and may involve seed burial - Berg 1975), fruiting at ground level (as noted by Carlquist 1976 for some Australian and South African genera), and seed burial mechanisms (Naveh 1975). Little is known of the fate of buried seeds but various predation and decomposition losses may be envisioned. Keeley (1977) points out that the soil seed bank in chaparral is the result of dynamic fluctuations in seed inputs and outputs.

INTERACTIONS BETWEEN ADAPTIVE TRAITS

Some combinations of traits are most unlikely to occur together.

Below, the co-occurrences of the four major adaptive traits identified above are considered. Because fire-stimulated dispersal is only possible and significant when on-plant storage occurs these characteristics are considered as one. Similarly, because fire-stimulated germination is only possible and significant if in-soil storage of seed occurs, these two are linked also.

Vegetative resistance to fire occurs for

both plants which store seed and for those which don't. Among plants with on-plant storage of seed, a fire resistant group of species would be the mallee eucalypts; a fire sensitive species with on-plant storage would be *Pinus brutia* (Naveh 1975). Examples of resistant and sensitive *Arctostaphylos* species with seed storage in the soil and the dynamics of their seed populations, are given by Keeley (1977).

Fire-stimulated flowering, as considered in this text, occurs only in fire resistant species. One could, however, consider that the California annuals which are stimulated to germinate by fire and which flower as a consequence of this show both in-soil storage and fire-stimulated flowering. Among perennials, the species which show fire-stimulated flowering - such as the orchidaceous geophytes and *Xanthorrhoea australis* - appear to have no seed dormancy mechanism nor on-plant storage. Examples of the co-occurrence of seed storage and fire-stimulated flowering may be found eventually among the in-soil storage group but are most unlikely to occur in the on-plant storage group.

The last interaction to be considered is between storage of seed on the plant and storage of seed in the soil. The presence of both in the same population of a species seems most unlikely because seed storage on the plant, and the release of seed at the time of fire, foreshadows conditions for germination that will be optimal soon after fire. A seed dormancy mechanism, necessary for soil seed storage, would run counter to the attainment of maximum germination in the pyrogenic seed bed.

DISCUSSION AND CONCLUSIONS

1. *Traits considered adaptive to fire may be distinguished as: vegetative survival through bud protection and resprouting; enhanced reproduction facilitated by fire-stimulated flowering; enhanced reproduction facilitated by on-plant seed storage with fire-stimulated dispersal; enhanced reproduction facilitated by in-soil seed storage with fire-stimulated germination.*

From Dobzhansky's (1956) definition of an adaptive trait the above traits have been considered to be adaptive to fire. This conclusion, however, needs to be considered in the light of the other conclusions below (e.g., number five) if its significance is to be put into perspective. For example, while vegetative resprouting may be seen as an adaptive trait to fire, it can fail if fires occur very frequently over long periods.

Recently, flammability of the plant community has been treated as an adaptive trait by some authors (e.g. Biswell 1974). In the present account this property has not been considered. This is not to deny the existence of any feedback mechanism between community development and flammability as postulated by Mutch (1970) and others (Mount 1964, Jackson 1968) but rather to emphasize the stage in the development of research into this topic.

2. *A single trait like vegetative survival through bud protection and resprouting may be adaptive not only to fire but to other environmental variables as well e.g. insect attack, shade, disease.*

3. *Different species living in the same environment may be adaptive to fires in different, but equally effective, ways.*

Sprouting and non-sprouting *Arctostaphylos* provide an example. Also survival and reproduction of geophytes may occur differently from that for shrubs or trees or annual herbs but all may occur in the same environment in the same locality. This conclusion may also be seen to be a consequence of the interactions between traits.

4. *The significance of a trait and its adaptive value can only be considered within the context of the life cycle.*

A fire-sensitive species like *Banksia ornata* may be capable of producing woody follicles which fail to open until the passage of fire but such a trait can hardly be considered adaptive if the frequency of fires is such that the plant does not reach reproductive maturity. Similarly, sprouting behaviour is only significant if the longevity of the plant has not been exceeded. Other examples may also illustrate this self-evident conclusion.

5. *For fire as an environmental variable, adaptation must be considered in terms of the fire regime : type (i.e. peat or above-ground fire), season, frequency and intensity of fire.*

Examples of this may be found throughout this review (although type of fire has not been considered). Season of burn affected sprouting

response and flowering in some cases; frequency of fires affected sprouting response and was important to expression of adaptive traits; intensity of fire affected tree resistance, seed release from trees and germination of seeds. The fire regime and life cycle can interact with species characteristics so that either survival or death of a population in an area could occur. Thus, the adaptation of the species as a whole is to the fire regime rather than to a single fire.

5. *Fire is only one of a set of selective agents faced by a plant population. Traits which enable survival and reproduction during a succession of fires in the environment must also enable survival and reproduction during the stresses imposed by other selective agents.*

Seed stored on the plant and protected from fire damage by a thick wall is seed available for regeneration after fire-stimulated dispersal unless it has suffered from the ravages of vertebrate and invertebrate predators or from disease. Seed must therefore be protected from these biotic influences if the fire-stimulated dispersal of seed is going to be a successful strategy for reproduction. Certain energy costs are involved in protection and these need to be balanced against possible advantages in vegetative growth.

7. *Control of an adaptive trait, while triggered by the cue of fire occurrence, may be vested within the plant itself or it may be vested in the environment.*

The sprouting response usually occurs when the internal correlative inhibitions within the plant are broken by leaf removal through fire or other agents. Similarly, the flowering response of *Xanthorrhoea* and the control of hardseededness are subject to internal control. The flowering responses of geophytes, however, may be controlled by post-fire ambient conditions. Another example, a better studied one, would be the release of seeds of California annuals from allelopathic inhibition imposed by other species. The distinction between internal control and external control is perhaps one that is not clear-cut but it may enable a clearer picture of plant response to be perceived.

ACKNOWLEDGMENTS

For their useful comments on a draft manuscript I would like to thank Drs. R.H. Groves, J.E. Keeley and R.F. Parsons.

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POST-FIRE SUCCESSION OF PLANTS IN MEDITERRANEAN ECOSYSTEMS[1]

I.R. Noble and R.O. Slatyer[2]

Abstract: Classical ideas of succession have limited applicability to fire prone ecosystems. In order to derive more realistic patterns of replacement sequences in plant communities exposed to various fire frequencies, a small set of species attributes, vital to reproduction and survival, is defined. A classification scheme is then built up by assigning combinations of vital attributes to the key species in particular communities. The scheme appears to have both descriptive and predictive value when applied to three different types of Mediterranean ecosystems.

Key words: Eucalyptus, fire, Mediterranean, succession

INTRODUCTION

Classical concepts of succession (Cowles 1899; Clements 1916; Weaver and Clements 1937; Odum 1969) assume, that following a disturbance, the community gradually resumes the structure and composition of the surrounding undisturbed area by an orderly and predictable series of species replacements. The initial post-disturbance community is assumed to be occupied by colonizer, or pioneer species, which are unable to replace themselves indefinitely at the site. Progressive substitutions by other species occur until a suite of species able to replace themselves indefinitely occupies the site and the climax stage is attained. The whole process requires effective altruism on the part of the species of each of the early successional stages, since they alter the environment to make it less suitable for their own persistence and continued recruitment and more suitable for the recruitment of subsequent species. From this traditional view, fire has been regarded as an externally induced aberration which causes a regression in an otherwise progressive successional sequence.

The classical concepts have been challenged by several authors in recent times. Egler (1954) argued that the initial floristic composition of a community immediately after a disturbance can dominate the subsequent pattern of development. Drury and Nisbet (1971, 1973) have traced the history of successional thinking and suggested that, in most cases of secondary succession, the early stages can be understood in terms of differential growth, with species frequently acting to delay the succession of another community, rather than altruistically preparing its way.

Connell and Slatyer (1977) have proposed a broader system of successional processes incorporating the possibility of classical concepts, the mechanisms described by Egler, and Drury and Nisbet, and also a form of inhibited succession where species established early in succession hold the site to the exclusion of longer lived, later successional species. Invasion by longer lived species is dependent on chance establishment in gaps among the early species.

A meeting dealing with fire in Mediterranean ecosystems seems an appropriate place to discuss alternatives to the classical view of succession. For example, Hanes (1971) in describing succession in chaparral stated:

> The sequence of vegetation change in chaparral after fire is unusual. Shrubs composing the mature community

[1]Presented at the Symposium on Environmental Consequences of Fire and Fuel Management in Mediterranean Ecosystems, Palo Alto, Calif. Aug. 1-5, 1977.

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> are present in the vegetation the first year. Chaparral succession thus is set apart from the usual sequence of change that characterizes secondary succession in most plant communities. Also, invasion of the chaparral community by new species is very limited once the initial first-year population is established. A site once occupied by chaparral species will not return entirely to earlier seral stages.

His observations would be supported in many Australian communities. Indeed succession theory has had little application in Australia, probably because many of the communities do not fit readily into the classical framework.

Partly because of limited applicability of classical concepts, and partly because of new ideas and observations of the type just referred to, two major lines of work dealing with vegetation regeneration after a disturbance, such as fire, now seem to be developing. One approach emphasises the patterns of replacement sequences observed in plant communities. Egler (1954), Horn (1976) and Connell and Slatyer (1977) have all suggested sequences in addition to that originally proposed by Clements (fig. 1). However, these schemes do not attempt to relate the pattern of the replacement sequences to specific attributes of the species taking part in them. Nor do they directly relate the various pathways that are possible in the replacement sequence, to the disturbance regime.

The second approach emphasises the adaptive traits of the species involved in the disturbance and subsequent events. Naveh (1973) classified the Mediterranean woody plants of Israel into obligate and facultative resprouters depending on whether they are entirely dependent on vegetative recovery after a fire, or whether both vegetative and seed reproduction occurs. Gill (1975, 1977) has discussed the traits of Australian plants important in recovery from fire. Species adaptions are important in determining whether a species can survive a given fire regime, but they give little insight into the types of replacement sequences that might occur in communities containing them.

In this paper, which is an extension of Noble and Slatyer (1977), we seek to define a small set of species attributes vital to the reproduction and survival of a particular species when subject to periodic disturbances. We deal specifically with fire as the periodic disturbance. From this set of vital attributes, similar to those discussed by Gill, and Naveh, we derive replacement sequences like those of

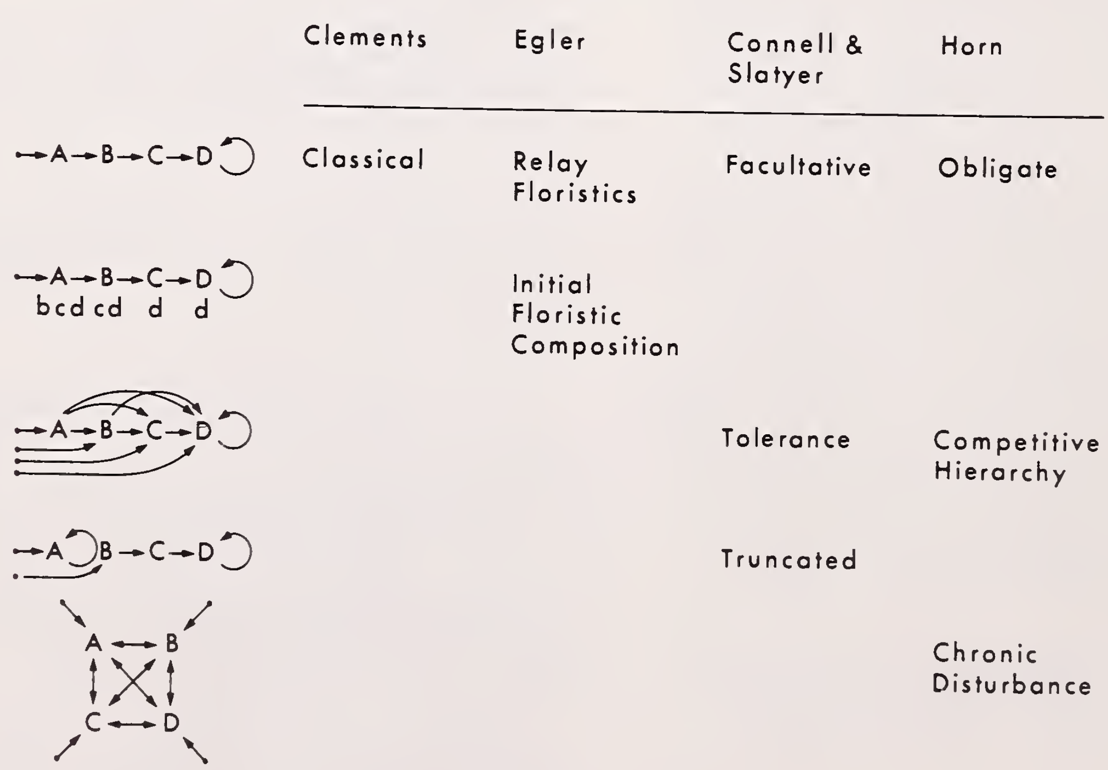

Figure 1-- Replacement sequences proposed by several authors. The letters represent hypothetical dominant species; upper case indicating dominance, and lower case subdominance. The arrows marked with a dot show the alternative starting points for the replacement sequence after a disturbance.

Horn, or Connell and Slatyer. First we will describe three examples of Australian Mediterranean ecosystems so that we might use them as examples in subsequent discussion.

THREE MEDITERRANEAN ECOSYSTEMS

As our first example, we will deal with mallee-Callitris communities in western New South Wales. Mallee is a shrub-like multi-stemmed form of eucalypt found mainly in Mediterranean climatic zones in Australia (200 to 600 mm yr^{-1} of predominantly winter rainfall). About 130 species of Eucalyptus show the mallee habit and all have a very long lived underground lignotuber from which they can resprout after fire or mechanical damage. Seedlings are rarely observed.

Callitris columellaris F. Muell. (White Cypress Pine) is a slow growing conifer up to 25 m tall, which produces useful timber. It has a wide distribution and is found in the mallee district mainly on sandy soils. In general mallee and Callitris are segregated in distinct dominance communities, but in some areas the two species occur in closely interwoven patches, with small groups of Callitris trees scattered throughout the mallee. Callitris regenerates from seed and it can reach reproductive age as young as 6 yr. The seed is winged and is usually released from the cones during summer, but with limited dispersal (up to 400 m, Lacey 1972). It can form very dense regeneration stands under the canopy of older trees or of other species.

There is little understory in dense mallee-Callitris stands, however the mallee species produce fuel in the form of ribbon and decorticating bark so that a community with a high mallee component readily carries fire. If a fire, hot enough to kill all above ground tissue, occurs in a mallee-Callitris community, then the mallee species will resprout from the lignotubers. Usually sufficient seed will survive the fire to initiate Callitris regeneration from seedlings. There will also be growth of some shrub species and grasses, mainly from seed. The grasses are gradually suppressed as the trees regenerate. Dense Callitris stands are less likely to carry a fire than the mallee species so usually a few Callitris trees survive to act as seed sources.

A second example is that of a dry sclerophyll forest dominated by Eucalyptus and legume species. Purdie and Slatyer (1976) and Purdie (1977a,b) have described succession after fire in a community near Canberra which, although not strictly Mediterranean (600 mm of annual rainfall but with relatively wet summers), is still representative of other dry sclerophyll communities.

The community includes a tree stratum up to 15 m high, of Eucalyptus macrorhyncha F. Muell. ex Benth., E. rossii R.T. Baker et H.G. Smith and several other eucalypts all of which have long lived lignotubers. A tall shrub layer up to 2 m high includes Acacia genistifolia Link, Daviesia mimosoides R. Br. and Dillwynia retorta (Wendl.) Druce. These shrubs are short lived compared to the eucalypts and tend to mature in about 5 years and die after about 15 to 20 years. There is also a minor shrub and grass understory. After a fire the eucalypts regenerate quickly, mainly from epicormic buds and lignotubers. The smaller species usually suffer more physical damage during a fire, but Daviesia regrows from root stocks and appears to dominate the understory in the first few years. However, the Acacia and Dillwynia regenerate from long lived seeds which survived the burn stored in the soil and, after several years, they become codominate in the understory. Little successful regeneration of any of these species occurs during unburnt periods. Therefore if the area remains unburnt for a long period, the tall shrub layer senesces and is lost.

A third example is the heath community in the south east of South Australia described by Specht et al. (1958). The heaths occur on deep sands which are extremely poor in nutrients, in a Mediterranean climate which receives about 500 to 600 mm of rainfall, mainly in winter. The community is made up of a number of sclerophyllous species and rarely exceeds 1 m in height.

Fires are frequent in this community, and within 5 yr of a fire there is sufficient fuel to carry another. A fire kills all aerial growth and consumes most of the above ground material. Soon after the fire several species sprout from underground root stocks. Initially Xanthorrhoea australis R. Br. dominates the community, but it is soon joined by Casuarina pusilla, Macklin., which is also a sprouter, and several herb and grass species which have widely dispersed seeds. After 3-10 yr C. pusilla becomes more dominant along with Banksia ornata F. Muell. which regenerates from seed. If the site remains unburnt for more than about 25-35 yr, C. pusilla and B. ornata begin to senesce and are not replaced. After about 50 yr Banksia marginata Cav. and Xanthorrhoea australis are dominant. B. marginata is a sprouting species and is able to maintain itself in the community by suckering. Specht did not observe any new seedlings of X. australis, but individuals are very long lived, and vegetative division of the stocks seemed

to have approximately balanced any mortality of the plants during repeated fires.

Based on the observations mentioned above, and many similar situations with which you are probably familiar, we wish to make several points about vegetation replacement sequences at a particular site.

1. Initial recruitment depends on the presence of propagules immediately after the disturbance. The propagules can either arrive from elsewhere, or they may persist through the disturbance at the site either as seed or as some form of vegetative propagule.

2. Immediately after the disturbance there is a period of rapid recruitment in conditions of little competition.

3. After the initial pulse, recruitment slows, since once an individual plant is established it is very difficult to displace. Unlike animals, where individuals may be physically displaced by interactions with other individuals, the displacement of a plant requires its death and the creation of a gap, or the physical dominance and take-over of its living space. Both processes take time, and long lived species are at a great advantage in retaining a presence in the community. The longevities of many plant species compared with animal species may be a reflection of the adaptive advantage conferred by longevity in many situations.

4. Therefore, during and immediately after the initial pulse, species which have propagules present, can establish rapidly, and are long lived, have an advantage.

5. After the initial pulse, species with the ability to regenerate and grow in situations of limited resources have the advantage.

VITAL ATTRIBUTES

These points can be summarised by considering which attributes of a species are vital to its presence at a site subject to periodic disturbances. We see the following vital attributes as the most important:

1. The method of arrival or persistence of propagules at the site after a disturbance.

2. The conditions in which the species establish and grow to maturity.

3. The longevity of the individuals, and the time taken to reach critical stages in their life history.

We consider that these three attributes determine the main features of vegetation replacement sequences. In addition if some indication of relative importance or dominance is needed, we would add a fourth attribute:

4. The growth rate of a species.

Method of Persistence

The first vital attribute deals with the method of persistence through the disturbance. We recognise four different mechanisms.

1. Persistence by the arrival of vagile seeds (D). The seeds of species which have powers of dispersal from surrounding, undisturbed areas are always available at the site in sufficient quantity for restocking.

2. Persistence via seeds with long viability and often stored in the soil(S). These seeds are available for a significant period (in some cases centuries) after the loss of adults from the site and it is assumed that the seed pool can persist through several disturbances without replenishment (i.e. not all seeds germinate after the first disturbance).

3. Persistence by seeds surviving the disturbance at the site often within protective cones or fruits held in the canopy (C). In this case the seeds are available only if adults were present at the site immediately before the disturbance.

4. Persistence by all or part of an individual surviving the disturbance and then rapidly recovering, via vegetative regrowth, from any damage (V).

Conditions for Establishment

The second vital attribute deals with the conditions necessary for establishment (i.e. germination or initiation and growth to maturity) in the community. We recognise three different mechanisms.

1. Able to establish at any time, if necessary, with adults of both the same species and of other species occurring at the site. These species can tolerate competition (T).

2. Able to establish only immediately after a disturbance when competition is usually reduced. These species are intolerant of competition in established communities (I).

3. Unable to establish immediately after a disturbance, but able to become established once mature individuals of either the same or another species are present. These species have some requirement which is only provided by established communities (R).

Life History

The third vital attribute deals with the life history of the species taking part in the replacement sequence. Life histories are important in determining the exact role a species can play in the community when a disturbance occurs. We describe four critical events in the life history of a species in order of occurrence after a disturbance (time 0).

1. The replenishment of sufficient propagules to survive another disturbance (*p* in figure 3). For D, S and V species propagules are available immediately and therefore *p* coincides with 0. With type C species there is a delay before a new batch of seed is available.

2. Maturity is the time at which individuals will have recovered or grown sufficiently to be regarded as established (*m*). This is a difficult event to define, but we have chosen to use the time when the individual is able to contribute propagules to the propagule pool that will enable the species to persist another disturbance. This occurs at sexual maturity in the case of D, S, and C species. Type V species are regarded as being mature immediately after the disturbance. This is obviously true for species which survive the disturbance. virtually unscathed, and those species which have to resprout from rootstocks are usually able to survive another disturbance even if it occurs soon after the first.

3. The senescence and loss of the species from the community (ℓ). Individuals of type I species eventually reach their maximum life span and senesce then die, and the species is lost from the community. Type T and R species are effectively immortal in an undisturbed site since they show continual recruitment.

4. Loss of propagules from the site so that the species is extinct (*e*). This can only occur with type I species since type T and R species, once established, always have mature individuals at the site. Nor can extinction occur with type D species since it is assumed that there are always mature individuals within dispersal distance of the site. With type C and V species, *e* coincides with ℓ since the loss of mature individuals implies the loss of the method of persistence, whereas with S species, *e* occurs after ℓ, the time span depending on the longevity of the stored seed.

The life history attribute determines critical phases in the recruitment, persistence and elimination of species from the replacement sequences. Application of the attribute adds more detail to the basic structure of the replacement sequence which is determined by the first two vital attributes.

Combinations of Vital Attributes

We can illustrate this classification scheme with some examples, dealing initially with the first two vital attributes. Many widely dispersed grasses and herbs act as fire weeds and rapidly occupy a disturbed site after a fire by germination of highly vagile seeds (i.e. D). However most of these species are relatively intolerant of competition for light and do not continue establishing on the site after the disturbance. They are therefore classified as DI. Ceanothus cuneatus (Hook) Nutt. (Wedgeleaf ceanothus) is a non-sprouting chaparral species which establishes from a seed pool stored in the soil immediately after a fire (S). However, once the chaparral community is mature, wedgeleaf ceanothus is no longer able to establish and it eventually dies out after about 50 years (Biswell 1974). Hence the appropriate classification is SI.

In this volume, Gill (1977) has described the adaptive traits of several Australian species. Most eucalypts have a mechanism for vegetative persistence through a fire (V), and very little recruitment of new individuals occurs during periods between disturbances, most seedlings remaining as stunted advance growth (I). Such eucalypts are therefore classified as VI. A small group of eucalypts are very poor resprouters, regenerating instead from a seed pool held in capsules in their canopies (C). These seeds fall on to the ashbed after a fire and establish rapidly. Recruitment between disturbances is also poor in this group (I), which therefore is best classified as CI.

The descriptions of the fire adaptions of Banksia ornata described in this volume (Gill 1977) show that this species is best classified as a CI species. The closely related species B. marginata does not store seeds in any fire resistant manner. However, it sprouts from underground tissue after a fire. Sprouting can continue to occur throughout the life span of B. marginata and there is a continual input of young vigorous sprouts, so maintaining the presence of the species

within the community. Hence B. marginata is best classified as a VT species.

Certain deductions may be made about the properties of species with different combinations of mechanisms of the first two vital attributes. First, it must be recognised that a species can be present in a community in one of three states; as a propagule (seed), as a juvenile or as an adult. A fourth possibility is that the species is extinct; no longer present in one of the other three states. The transitions between these states can be deduced directly from the mechanisms of the first two vital attributes. For example, if an SI species is present as a juvenile then, if no disturbance occurs, it will become an adult, and eventually the adults will die, leaving long lived propagules stored at the site. Eventually, if no disturbance occurs, these propagules will lose their viability, and the species will become extinct. If a disturbance occurs at any of the stages before extinction, then seeds from the seed pool will germinate and the species

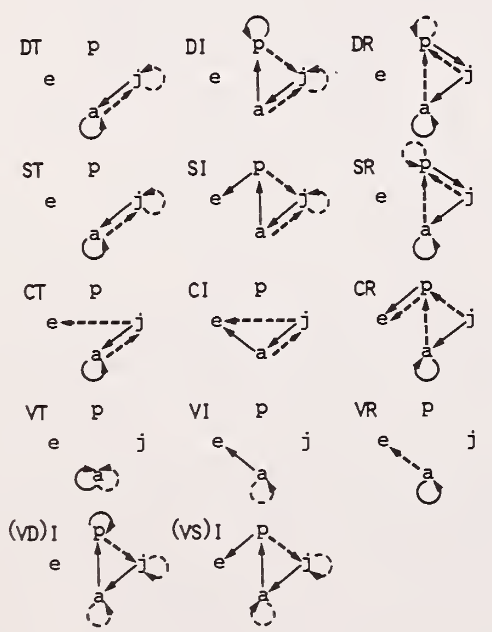

Figure 2-- Transitions between states for each combination of mechanisms of the first two vital attributes. The states are: p, present only as propagules; j, present as juveniles (and possibly propagules); a, present as adults (and possibly propagules and juveniles); e, extinct from the community. Solid arrows show transitions in periods with no disturbance, and broken line arrows show the transitions due to fire.

will be present in the juvenile state. The transitions for the other pairs of mechanisms shown in fig. 2 can be derived in a similar manner.

Several conclusions can be drawn from the transitions. For example, the pattern of transitions for DT and ST species are identical, and therefore they interact in exactly the same way in replacement sequences. Similarly DR and SR are exactly equivalent. The transitions for both CR and VR indicate that these combinations of mechanisms are most unlikely to occur. This is because the V and C mechanisms imply that the propagules are short lived and therefore will only be effective for a short time after a disturbance, whereas the R mechanism implies that the propagules cannot germinate or establish until some time after the fire. Therefore the number of effective and different mechanism pairs is reduced from 12 to 8.

It is possible that some species will show a combination of mechanisms associated with the first vital attribute. The D mechanism means that seeds are available at all times, and therefore there is no additional advantage to a D species also having S or C mechanisms. Similarly, species with an S mechanism will have seeds available at all the times that a C mechanism will provide seeds. Therefore there is a strict hierarchy of seed based mechanisms with D more useful than S, and S than C. If any species does show a combination of seed based mechanisms of persistence, then we need consider only the highest mechanism in the hierarchy.

However, it is possible for a species to have a V mechanism in combination with other mechanisms. An analysis of the transitions shows that the only combinations showing transition patterns different from those of the simple pairs of mechanisms are V with D and V with S, and then only when combined with the I mechanism of establishment (i.e. (VD)I and (VS)I). The transition patterns are only minor variations of the DI and SI patterns. These combinations of replacement sequences are probably common. For example Adenostoma fasciculatum H. et A. (chamise) is a vigorous sprouter which also germinates from dormant seeds in the first rainy season after a fire but not in later years (Horton and Kraebel 1955; Hanes 1971). It is therefore a (VS)I species.

Many V species also show the C mechanism and produce seedlings along with sprouts (e.g., Daviesia mimosoides, Purdie and Slatyer 1977). These seedlings help balance any mortality due to the disturbance, but they do not affect the role the species plays in any replacement sequences.

In figure 3 the life history characteristics of species with various combinations of the first two attributes are given. Even though four critical events in the life cycle are defined for most vital attribute combinations, the age at which most of these events occur does not need to be determined for the different vital attribute combinations. For example, for a VI species only its longevity need be determined since propagule replenishment and maturity occur immediately after a fire, and extinction coincides with the loss of the species from the community at the end of its life span. For a VT species, not even the longevity need be known since the species will show continuous recruitment, and therefore is effectively immortal. Only for SI species do the ages of three events need to be known, i.e. age at maturity, the longevity and the life span of the seed store. Therefore, again a simplification of the complete scheme can be obtained from deductions about the vital attributes.

APPLICATIONS OF VITAL ATTRIBUTES

We will now apply the vital attributes discussed above to the examples of Mediterranean ecosystems described earlier. In doing so, we will demonstrate that a knowledge of the vital attributes of the species occurring at a site enables replacement sequences to be predicted

critical events

	$0 — p — m — \ell — e — \infty$
DT	$0p$ ——— m ——— $\ell e\infty$
DI	$0p$ ——— m — ℓ ——— $e\infty$
DR	$0p$ ——— (m) ——— $\ell e\infty$
ST	$0p$ ——— m ——— $\ell e\infty$
SI	$0p$ ——— m — ℓ — e — ∞
SR	$0p$ ——— (m) ——— $\ell e\infty$
CT	0 ——— pm ——— $\ell e\infty$
CI	0 ——— pm — ℓe ——— ∞
VT	$0pm$ ——— $\ell e\infty$
VI	$0pm$ ——— ℓe ——— ∞
(VD)I	$0pm$ ——— ℓ ——— $e\infty$
(VS)I	$0pm$ ——— ℓ — e — ∞

Figure 3-- Life history characteristics for various combinations of mechanisms of the first two vital attributes. The critical events are described in the text. The (m) for the R species indicates that their reaching maturity is dependent on the presence of other mature individuals.

under various patterns of disturbance frequency. In the replacement sequences depicted below, a species will be included in the symbolic description of the community only if it is represented in the community by adults. That is, only if it is between events m and ℓ in its life history. This period approximately coincides with the period during which most observers would empirically recognise the species as being important in the community. Solid lines are used to represent the transitions which occur in the absence of a disturbance, while dashed lines indicated the transition when a hot fire occurs.

First we deal with the Callitris-mallee community. The mallee species are typical of the majority of the eucalypts, and therefore are described as VI species. The only information needed about the life history of a VI species is its longevity (figure 3). We do not know the longevity of an individual mallee lignotuber, but it is probably of the order of several centuries. Callitris appears to be a CT species. It takes Callitris seedlings about 6-8 yr (Lacey 1972) to reach maturity, which is all that we need to know about its life history. The grasses and some minor shrubs appear mainly to be species with vagile propagules, and intolerant of competition with a mature tree stratum. They may be classified as DI species which reach maturity in 1 to 2 years and die out after a decade or so.

Initially we will describe, in detail, the derivation of a replacement sequence, considering only the tree species (figure 4a). We consider a site which is already supporting a stand of both mature mallee and Callitris (i.e. VI + CT). If this site is burnt by a hot fire, the above ground tissue of both species will be killed. The V species will regenerate immediately and the first stage of the replacement sequence will consist of only the mallee (VI). Seedlings of the C species will germinate as soon as suitable weather conditions occur, however mallee will remain the only 'mature' species until the Callitris seedlings reach maturity after about 6-8 yr so returning to a VI + CT community. If the community remains unburnt for a very long time the mallees will die out, leaving only Callitris (CT) which is self perpetuating. Therefore the undisturbed replacement sequence is :

$$\mathrm{VI} \xrightarrow{\text{6-8 yr}} \mathrm{VI} + \mathrm{CT} \xrightarrow{\text{100 yr?}} \mathrm{CT} \circlearrowright$$

However fires will usually disrupt this sequence. We have already considered the effect of a fire at the VI + CT stage in deriving the above sequence. If a fire occurs at the VI stage (i.e., within 6-8 yr after the first fire), then the young, immature Callitris will be destroyed

and Callitris will be lost from the community, or at least substantially reduced in importance. This is shown in figure 4a by the transition VI ---→VI, If the resultant VI community is burnt again then it will be relatively unaffected. If it remains undisturbed for a very long period, and the mallee begins to die out the replacement sequence will be difficult to predict (hence VI ⟶?).

If the CT community eventually burns after the long period without fire, the Callitris will regenerate from its seed pool. The mallee will not be able to regenerate since it is a V species and it has been lost from the site. Only D or S species can re-establish on a site once the adults have senesced and died.

Therefore even this simplified sequence shows some interesting points. The most common replacement sequence is probably,

VI ⟶ VI + CT

with fires occurring every few decades. However, the long absence of fire can lead to the loss of the mallee, while a high frequency of fire can lead to the loss of the Callitris.

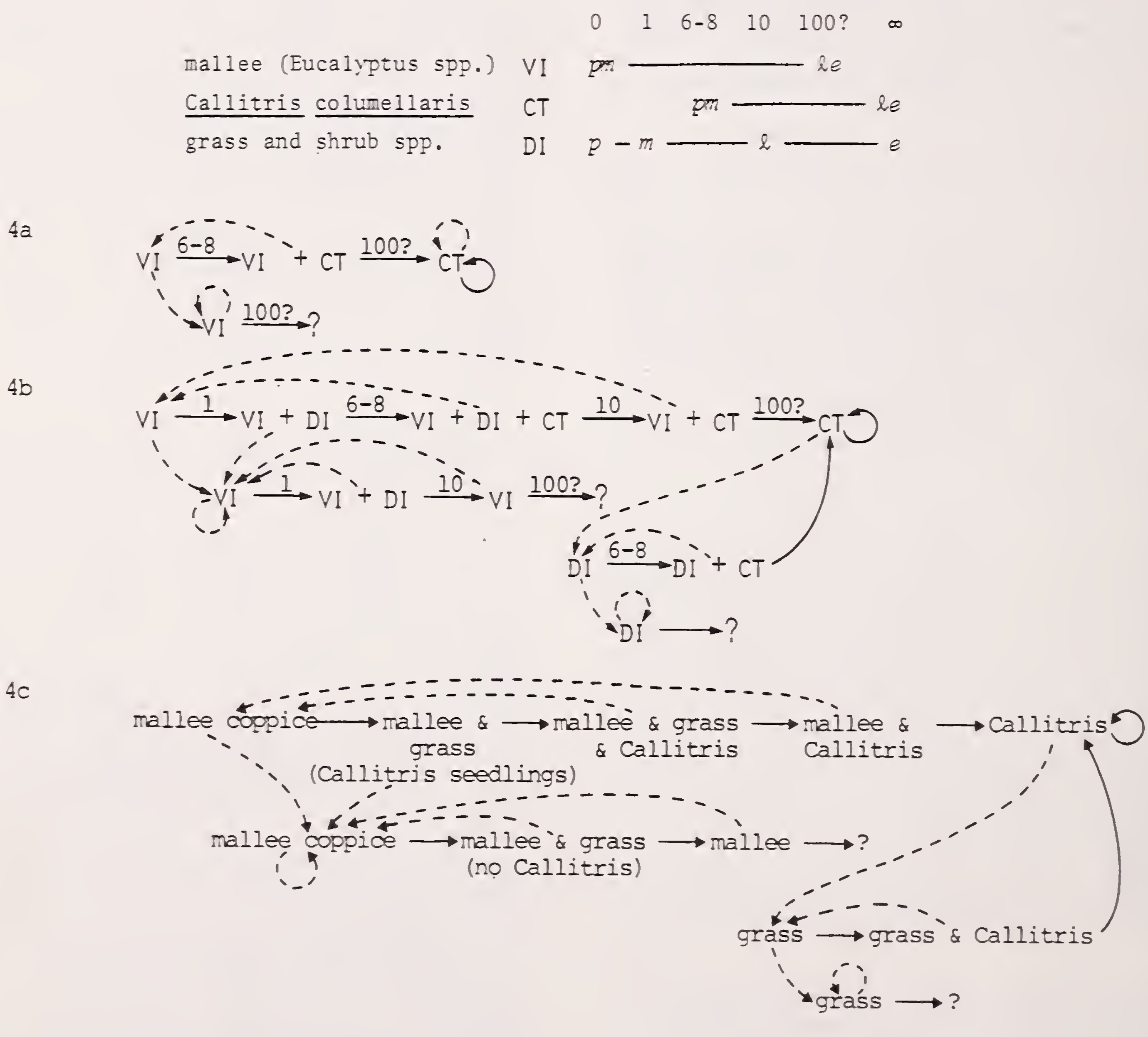

Figure 4-- Species replacement sequences in a mallee-Callitris community. The approximate time taken (in yr) for transitions in undisturbed communities is shown above the solid arrows. The broken line arrows show the transitions caused by fire. 4a shows the replacement sequence generated by considering only the trees, while 4b and 4c show an expanded sequence considering the trees and grasses.

A more realistic replacement sequence can be derived by including the grass and shrub species (fig. 4b and 4c). The replacement sequence in 4b is essentially the same as that depicted in 4a, but with the role of the grass and shrub species shown in detail. The sequence emphasises the sensitivity of Callitris to frequent fires both when it occurs with mallee and in pure stands. It can be seen that the sequence derived in figure 4a is an adequate precis of the more complete sequence shown in figure 4b. We find that for many plant communities the essential features of any replacement sequence can be depicted by dealing with a pair of the most important species, or in some cases a sequence of several pairs of species.

At this stage it is important to emphasise that the replacement sequences shown in this paper refer to the changes in species composition at a given site, assuming constant edaphic and climatic conditions. Therefore, although the replacement sequences derived in figure 4 indicate that, under certain fire regimes, stands of pure mallee and stands of pure Callitris can be derived from what was originally a mixed stand, this does not necessarily mean that all pure stands are derived in this way. At many sites the edaphic or climatic features favour either Callitris or mallee rather than a mixed community.

The second example deals with the dry sclerophyll woodland described above. The replacement sequence derived for this group of species is shown in figure 5. Again the Eucalyptus

		0 3 20 100?
Daviesia mimosoides	VI	pm —— ℓe
Acacia genistifolia	SI	p — m — ℓ — e
Dillwynia retorta	SI	p — m — ℓ — e
Eucalyptus spp.	VI	pm ———— ℓe

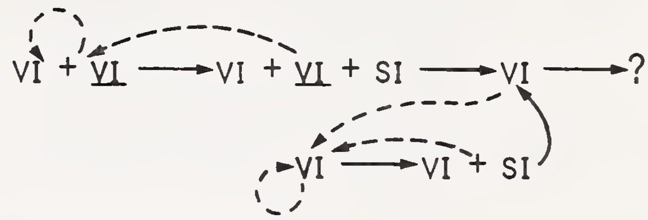

Figure 5-- The species replacement sequence for a dry sclerophyll woodland near Canberra.

species are classified as VI, with a life span of probably a century or more. Daviesia mimosoides is also a VI species but with a life span of only about 20 yr. Dillwynia retorta and Acacia genistifolia are SI species, which mature in 2-3 yr and also have a life span of about 20 yr. The longevity of the seed in the soil is not known but it is at least many decades. The sequence indicates that the fully diverse community will only be maintained by burns at intervals of less than 20 yr. If a longer period without a burn occurs then a eucalypt community with a more open understory will develop. It is of interest that this scheme shows that Daviesia is endangered by long protection from fire since it does

		0 1 5 35 100? ∞
Xanthorrhoea australis	VI	pm ———— ℓe
Casuarina pusilla	VI	pm ——— ℓe
Banksia marginata	VT	pm ————— ℓe
Banksia ornata	CI	pm — ℓe
herbs	DI	p — m ———— ℓe

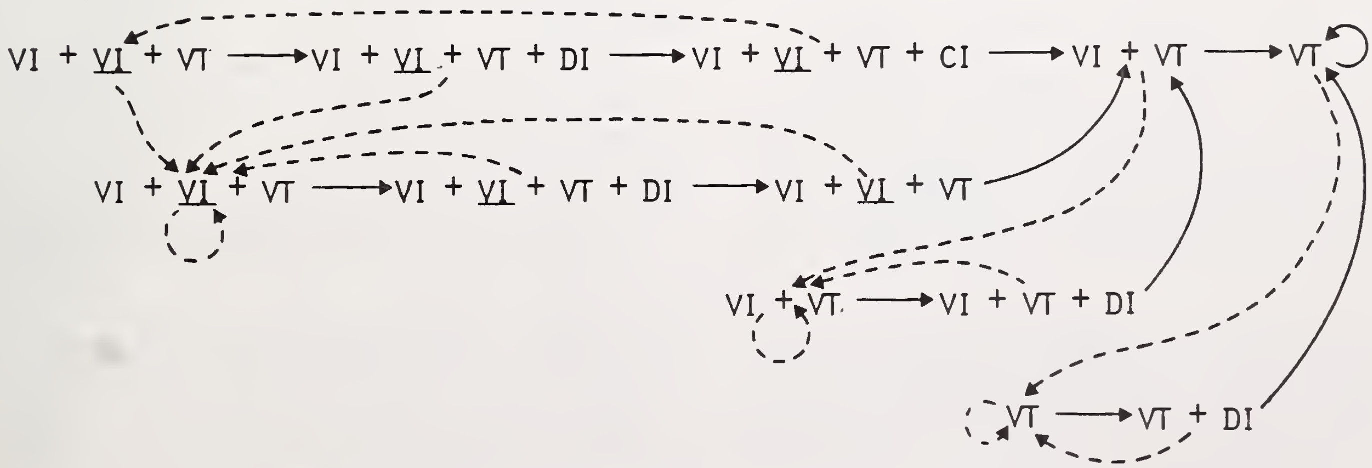

Figure 6-- The replacement sequence for a heath community as described by Specht et al. (1958).

not have a long term method of maintaining propagule availability in the absence of fire.

The final example is that of the heath community. We will not describe the derivation of the replacement sequence in detail, however the vital attribute data, and the sequence are shown in figure 6. The sequence indicates that full diversity can only be maintained by burns more frequent than once every 35 yr. It is interesting to note that Specht could not find a site which has remained unburned for greater than 25 yr in his study area. The sequence also shows that Banksia ornata can be lost from a community if frequent burns occur.

The foregoing examples suggest that the vital attributes described here can form the basis of a classification scheme which has both descriptive and predictive value when applied to natural communities exposed to various fire frequencies. The predictions appear to have biological realism; for example indicating fire frequencies which are needed to retain all species in a community as well as those which are likely to lead to extinctions. This scheme is still being reviewed and tested against a variety of field situations in order to make it as rigorous and widely applicable as possible. We also hope to prepare a more formal statement of the scheme drawing on ideas from linguistic analysis, and relating the replacement sequences derived from this approach to those outlined by other workers.

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DECOMPOSERS AND THE FIRE CYCLE IN MEDITERRANEAN-TYPE ECOSYSTEMS[1]

N. S. Margaris[2]

Abstract: The available to soil microbes energy,by theoretical estimations,seems to maintain total soil metabolism unchanged during first post-fire year.A subsequent decrease is expected for the second year while later on a restoration of soil metabolism must take place as a consequence of the increased primary productivity.The available field data concern only with first post-fire year and comprise information on microbial numbers and activity, cellulose decomposition rates,nitrification as well as total soil metabolism.
Key words: Decomposers,fire,chaparral,phrygana.

INTRODUCTION

During a fire such temperatures are developing on soil surface that have as a result the killing of a great proportion of microorganisms living in its first centimeters.After that,and except for the quick oxidation of organic substances with the production of ash and charcoal, physical and chemical changes(texture, acidity,organic content etc) take place in the soil,also having a direct effect on microorganisms.We can say,for instance that a change (usually an increase) in pH,occuring after fire,has a direct effect on soil bacterial populations for the reason that the pH is a critical factor of bacterial growth.On the other hand, as Alhgren (1974) mentions,the non-existence of direct economic value and the techniques used in soil microbiology resulted in making our present knowledge on the changes of microbes after fire significant deficient in relation to our knowledge on higher plants and vertebrates.

It must be also mentioned here that the biological variety of this heterogeneous group of soil microoganisms and all the known kinds of interaction between them and also among them and higher plants and animals make the effort to generalize risky.However,having all the above in mind,we will try to cite in short what is known today to happen to bacteria and fungi after a fire.Our reference is made only for the first cms of soil ,where basically the changes occur.The research directions of soil microbiologists,with numbers given by bacteriologists and names by mycologists (Clark and Paul 1970),seem rather certainly,to be also valid in the case of fire research.

At first,as to the bacteria,their populations decrease just after fire (Hall 1921,Kivekas 1939,Fritz 1930, Ahlgren and Ahlgren 1965).If the soil is wet they multiply in a few days and become more numerous than before the fire (Corbet 1934,Ahlgren and Ahlgren 1965). In dry soils this increase appears after

[1] Presented at the Symposium on Environmental Consequences of Fire and Fuel Management in Mediterranean Ecosystems, Palo Alto,Calif.Aug.1-5,1977.

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the first rainfalls (Ahlgren 1974,Parkinson 1977).Naturally this soil recolonization is basically completed by the lower soil layers and by the wind from the neighboring areas.We consider as the main source the lower soil layers because in the case of a wet and sterilized soil fungi can advance in it at a speed of some cm per day (Evans 1955).Three reasons can be given to explain this augmentation of bacterial populations.The first one is the increase of pH which usually occurs after fire and is particularly beneficial to bacterial growth,as it is known bacteria prefer more than fungi alkaline environments. The second reason is the fact that by fire an addition of more easily available organic substances takes place and the third one that decomposition is accomplished faster when a rearrangement of the components of soil crumbs takes place which as a result has a greater contact between enzymes and organic matter and thus a faster rate of decomposition (Greenwood 1968).

As to the particular biological activities of bacteria,nitrification seems to increase after fire (Kivekas 1939,Ahlgren and Ahlgren 1960).The above mentioned reasons can be also valid here as an explanation(pH increase, ammonium addition, etc).The activity of free living nitrogen-fixing bacteria (Azotobacter and Clostridium) seems also to increase (Lund 1951) as well as the nodule bacteria into legume roots (Lunz 1934).

As to the fungi,quantitative measurements have shown a fall in their populations after fire (Wright and Tarrant 1958,Jalaluddin 1969,Schaefer 1974).There exist enough data on qualitative changes and the development of characteristic fungi in the burned soil is well known (Wicklow 1973,1974).Naturally, we possess more available data on Discomycetes,Pyrenomycetes and on Basidiomycetes because they produce fruit bodies visible macroscopically. Thus,it was found that these species multiply significantly after fire,fact shown even by their names (Pyronema ,Pyrophillus discomycetes etc).Something similar to mediterranean pyrophytes (e.g.Cistus sp) is happening to those species and it seems that their spores need a certain heat or chemical activation before germination (Sussman and Halvorson 1966).We must certainly mention here that the high presence of their reproductive forms does not necessarily mean the same for their vegetative part, the mycelium.

As to those fungi that complete their life cycle as mycelia or in the form of microscopic spores (Penicillium, Aspergillus etc) there exist today some available data.Thus,Widden and Parkinson (1975) showed that after fire occurs a decrease of the species Trichoderma and Penicillium in soils with Pinus contorta,while the species of Cyliodrocarpon destuctans remain unaffected. Meiklejohn (1955) found that species of Aspergillus take the place of Penicillium and Jalaluddin (1969) that Trichoderma and Penicillium are the first to recolonize the burned soil.

Concerning with ectotrophic mycorrhiza which exist on the roots of most plants (Parkinson 1976) little is known. However,according to Wright and Tarrant (1958) a fall was observed in their populations after fire.

MEDITERRANEAN-TYPE ECOSYSTEMS

The energetic point of view

As Clark (1968) mentions soil microbiologists believe that:"The supply of food materials in soil can be said to be perennially inadequate and there are many microoganisms in the soil and they are always hungry".Based on this principle let us attempt to face,in general,what can happen after a fire in mediterranean-type ecosystems.

We accept that the 2/3 of the plant biomass in the said ecosystems are found in the soil (Hellmers et al.1955,Rodin et al.1972,Margaris 1976).Having in mind that the plants in these ecosystems are adapted to fire,after which they regenerate by respruting it is rather obvious that the 2/3 of the biomass remain unaffected.It is certainly possible for a proportion of roots to be destroyed. In such a case the energy available to microbes increases.Concequently we can accept that the energy offered from roots to microbes will remain the same,for the first after the fire year,if not increased.

The aboveground plant biomass remaining in ash form after a fire is

estimated to be about 10-15% of the initial value of which nearly 40% in organic form (Christensen and Muller 1975) and therefore available for microbes.Conclusively,4-6% of the aboveground plant biomass represents the "energy offer"to microbes.Leaves of evergeen sclerophylls constitute 15-20% of total aboveground biomass (Lossaint 1973). Assuming that the leaf average life is 3 years,the "energy offer" as leaf litter to microbes is 5-7% of the aboveground biomass.So,we observe that during the first post-fire year the energy available to microbes is essentially maintened at the same level compared with previous years.Therefore we conclude that total soil metabolism before and during the first year after fire remains quantitatively unchanged.Of course,because of the change in the offered substances (for example a greater addition of ammonium) a certain differentiation in the activity of different physiological groups (e.g. nitrifying bacteria) is certainly expected.

After a fire,the capacity of the ecosystem for solar energy utilization is nearly nullified.During the first months after the subsequent rains plants regenerate and at the end of the growth period the aboveground biomass attains about 10% of the pre-fire biomass.In consequence a fall in the microbial activity will start existing from the second after the fire year and will disappear gradually following the increase in the primary productivity of the ecosystem.

It is certainly possible for small differences to appear during the microbial succesion,but in spite of this the long adaptation of mediterranean-type ecosystems to fire must not be considered as unrelated to corresponding microbial adaptations.

Experimental results

Microbial numbers

Before giving existing data on soil microbial populations measured after fire in mediterranean-type ecosystems,we must mention that they have only a relative utility because of many disadvantages in the pour-plate method of measurement(e.g. Phillipson 1971,Parkinson et al.1971). In table 1,however are listed results on the numbers of bacteria and fungi of a Californian chaparral ecosystem(Christensen and Muller 1975) and of a Greek

Table 1--Microbial numbers in burned and unburned soils of California (chaparral,Christensen and Muller,1975) and Greece(Arianoutsou and Margaris, unpublished data).

Item	Burned	Unburned
	(number of cells per g soil)	
1.B A C T E R I A		
1.1.Chaparral (California)	268×10^5	65×10^5
1.2.Phrygana (Greece)	68×10^4	28×10^3
2.F U N G I		
2.1.Chaparral (California)	447×10^4	9×10^4
2.2.Phrygana (Greece)	11×10^3	17×10^3

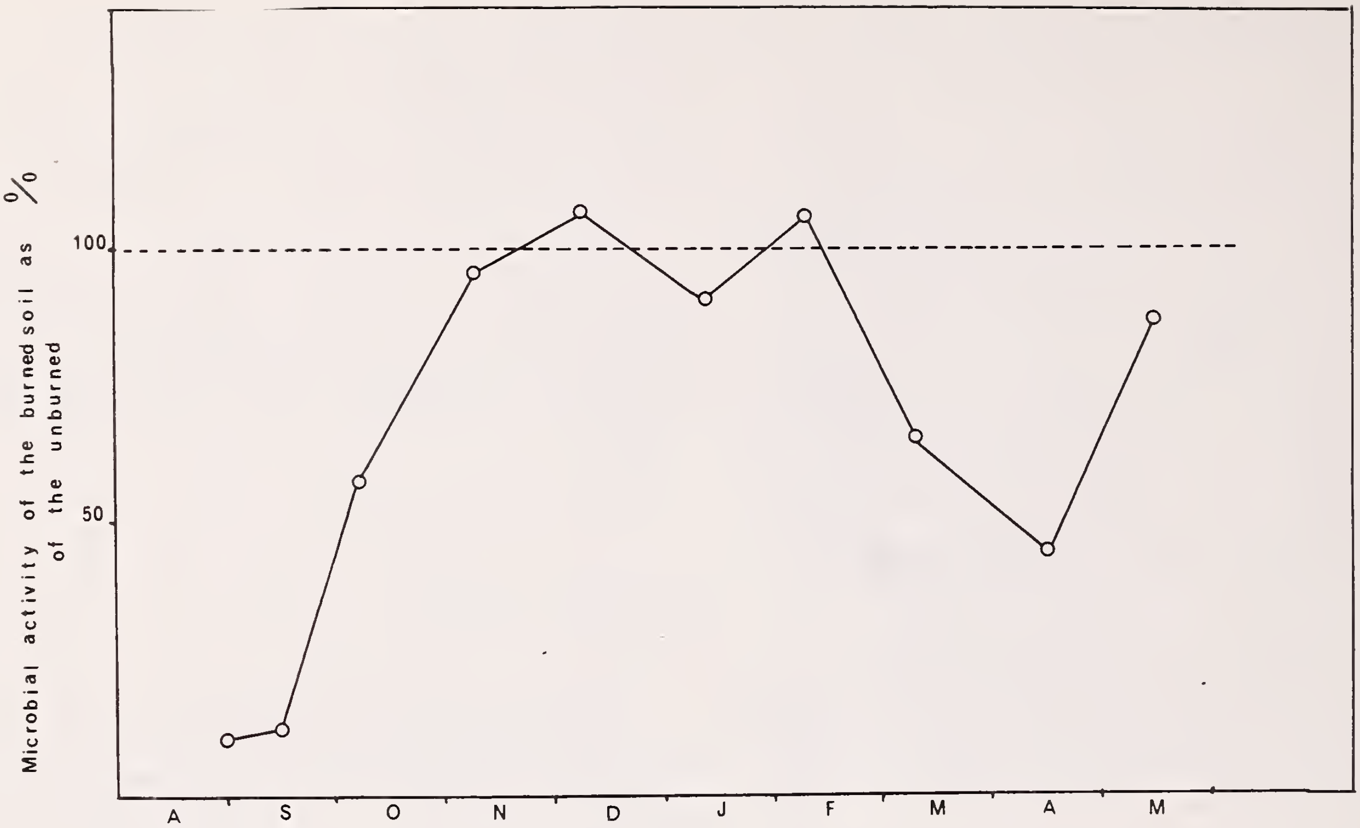

Figure 1--Microbial (dehydrogenase) activity in the burned soil (upper 5 cm) as percentage of the unburned one in Greece(Arianoutsou and Margaris,unpublished data).

phryganic ecosystem,both after fire.In the first case the measurements were carried out 9 months after fire,on June, while in Greece 3 months,on October.An increase in the numbers of bacteria is observed in both areas,while in what concerns fungi there exists an increase only in California.It must be mentioned here that by the pour-plate technique we isolate mainly the spores and not the fungal hyphae,and so the data from California do not necessarily show a higher microbial activity in the burned soil.

As to the microbial biomass in the first 5 cm of soil in a Greek phryganic ecosystem we found (Arianoutsou and Margaris,unpublished data),using the sterilization-reinoculation technique (Jenkinson 1966),that the microbial biomass in the burned area was 0.5 g per 100 g of soil ,2 months after the fire,30% less than the one in the unburned soil.

Microbial activity

Results concerning with soil microbial activity after fire are plotted in figure 1.We use as a parameter the activity of the enzyme dehydrogenase (Lenhard 1955).It can be observed that after fire and in a time period of four months the soil microbial activity reaches the level of activity in the unburned soil.After that a relative fall occurs.Unfortunately,there are no available data ,today,on what happens next.

Cellulose decomposition

Several soil microbiologists use nowadays the litter-bag technique in order to measure the decomposition rate of different substances in the soil. Cellulose,in the form of filter paper, is commonly used.Figure 2 presents data concerning with the decomposition of cellulose (pure or with the addition of urea) in both the burned and unburned areas.

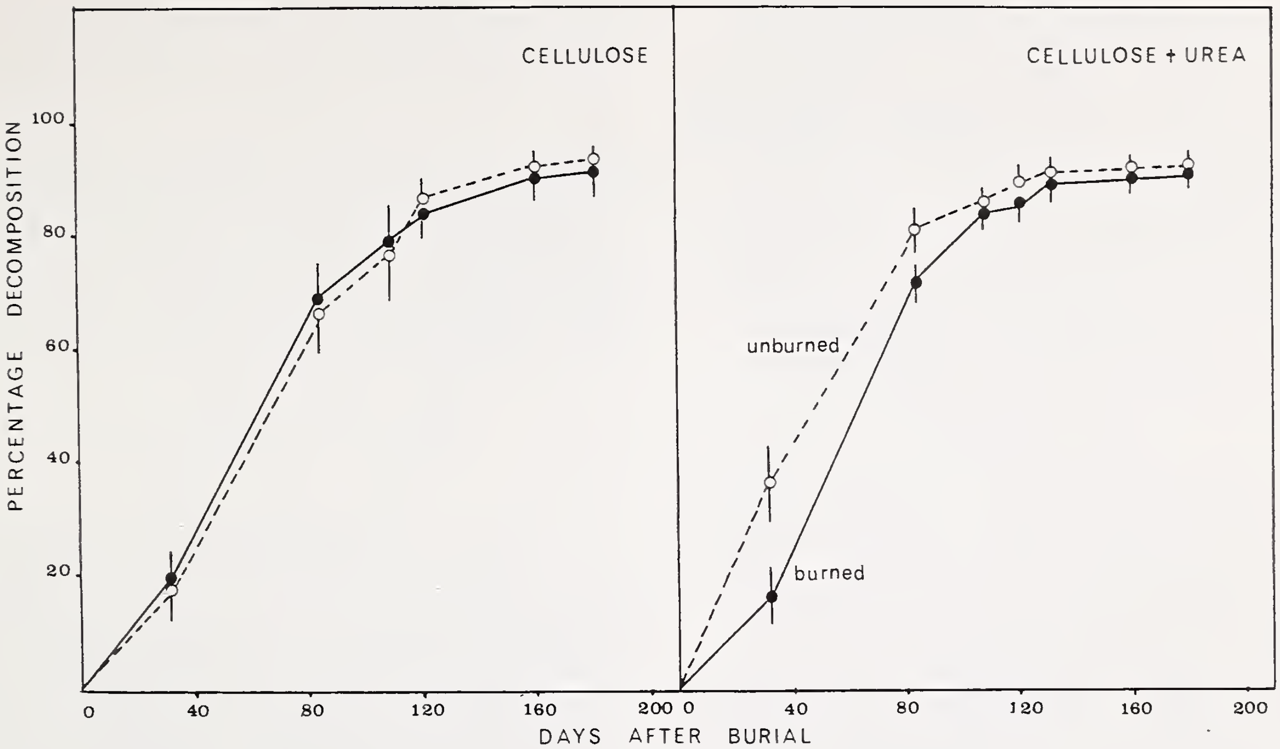

Figure 2--Decomposition of cellulose in burned and unburned soil in a phryganic ecosystem in Greece(Arianoutsou and Margaris,unpublished data)

We observed that in the case of pure cellulose the decomposition rates are identical,while in cellulose treated prior to burial with urea decomposition rate in the unburned soil was higher.

Nitrification

In 1973 Christensen presented interesting data on fire and on the nitrogen cycle in an Adenostoma chaparral in California.By measuring the quantity of ammonium and nitrates in burned and unburned soils and also in artificial clearings he came to the following conclusions:

1--With the addition of ash after fire, a high quantity of ammonium is added in the soil.
2--After the first rainfalls,an increase of nitrates is observed in the burned area,due to the nitrification because of the increased activity of the nitrifying bacteria after fire.
3--By measuring the quantity of nitrates in the unburned area and in the artificial clearings he comes to the conclusion that the appearance of nitrates in the soil after the rain is due to the leaching of leaves.This is proved from the fact that the first mms of rain were found containing high quantities of nitrates.
4-- As to the reasons the nitrification inhibition took place he mentions two of them.The first one is based on the toxins produced in the leaves during summer and the second one on the leaf structure of the chaparral plants which probably have a resistance to decomposition.

Before giving corresponding data on Greek phryganic ecosystems we consider necessary to make some comments on Christensen's concept of nitrification's inhibition in soils of unburned chaparral which is activated again after burning. As he reports this inhibition can be traced only in the case someone measures, at the same time,the level of nitrates droping to the soil because of the leaching of leaves when it rains.Anyway,it must be mentioned here that Lossaint's team in South France (see review by Lossaint 1973) observed a significant activity of nitrifying autotrophs in maquis with Quercus ilex ,measuring also the addition of nitrates due to leaching of leaves.

One more element which does not support Christensen's concept is that in his calculations he ignores the fact that

plants are continuously absorbing the nitrates pool. According to a work by Lossaint and Rapp (1971) the aboveground parts of a maquis with Quercus ilex need 4.6 g Nitrogen per m^2 yearly. Consequently the whole plant parts would need about 10 g/m^2, which they can absorb under the form of nitrates. The amount of nitrates droping to the soil because of the leaching of leaves is less than the 1 % of the above quantity. In consequence, it is difficult to accept the existence of an inhibition of nitrification.

Figure 3 contains results on the presence of nitrates in the first 5 cm of soil in the burned and unburned part of a Greek phryganic ecosystem. We observed that in the burned area the amount of nitrates increases earlier than in the unburned one, but afterwards falls to the same level. The differences observed between these two areas are perhaps due to differences in nitrification, but can also be attributed to the fact that plants use the nitrates for their growth since growing period has begun. This means that maybe nitrification is higher in the unburned area where, however, the produced nitrates are continuously absorbed by plants. To check this fact we collect every two months soil samples from both areas and when it reaches 60% of water holding capacity we let for 21 days in a dark room (25°C) and measure the initial and final amount of nitrates it contained. In this manner we measured the nitrifying capacity of the soil.

Corresponding data are given in figure 4 from where results that the nitrifying capacity after the fire was the same in both areas. During October it was higher in the unburned part. After that no significant differences existed till February. In April the nitrifying capacity was higher in the burned soil.

Total soil metabolism

Figure 1 presented the microbial activity in the first 5 cm of soil. The soil metabolism in the whole depth is given in figure 5. As a parameter we use the soil respiration measured in situ with the "inverse box" technique binding the evolving CO_2 with an alcali. No significant perturbation in the soil metabolism seems to be caused by fire. Calculating the total CO_2 amount produced from September 1976 till June 1977 we observed that 1168 g of CO_2 per m^2 were produced in the burned area while in the unburned one 1104 g CO_2 per m^2. These values are in complete accordance with what was previously mentioned on the available to decomposers energy. If the CO_2 evolution values are transformed to energy using

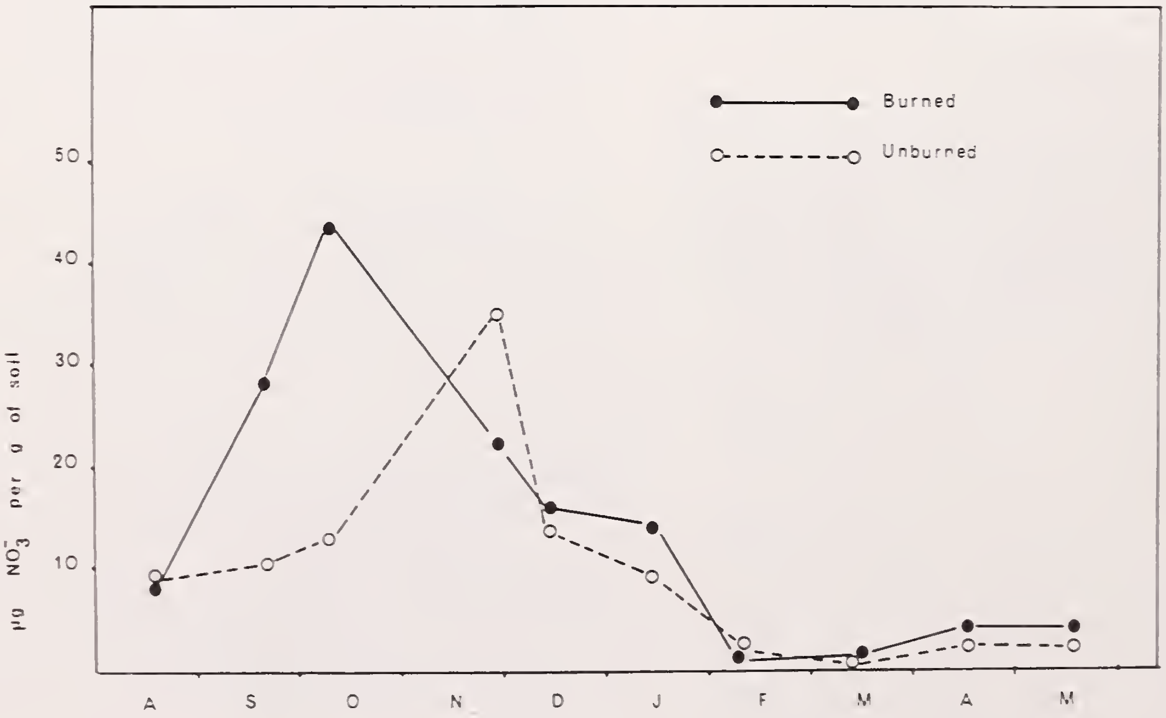

Figure 3--Soil nitrate content (upper 5 cm) in burned and unburned soil in a phryganic ecosystem in Greece (Arianoutsou and Margaris, unpublished data).

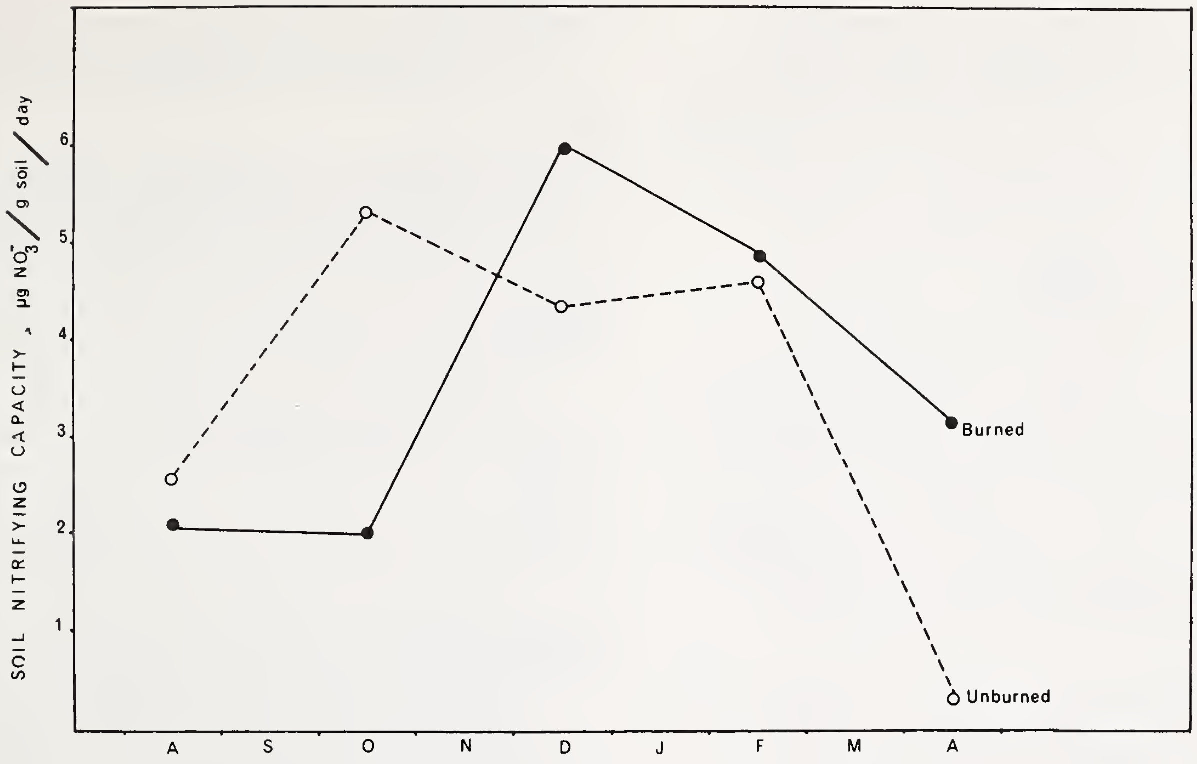

Figure 4--Nitrifying capacity in burned and unburned soil (upper 5 cm) in a Greek phryganic ecosystem (Arianoutsou and Margaris,unpublished data).

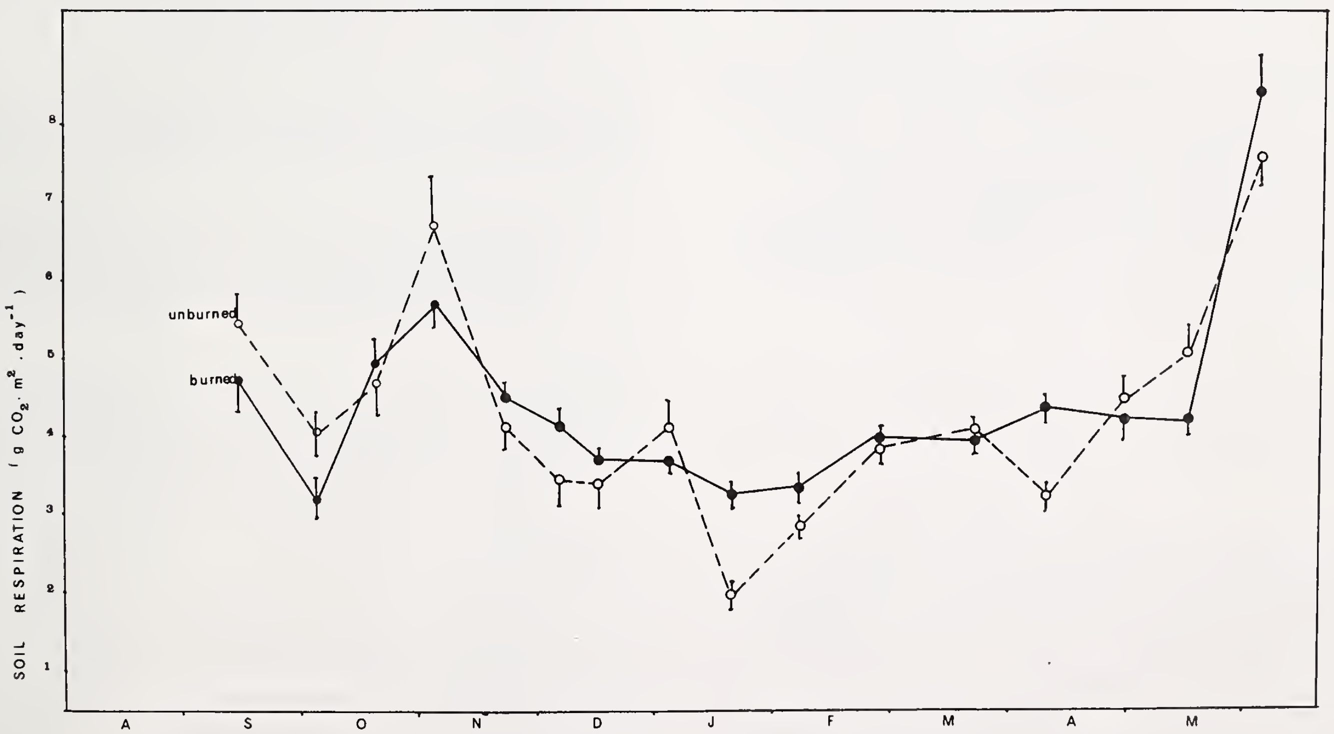

Figure 5--CO_2 evolution from burned and unburned soil from a phryganic ecosystem in Greece(Arianoutsou and Margaris,unpublished data).

Macfadyen's(1970) conversion factors, we observed that an energy amount of 3159 Kcal/m^2 was used in the burned area during the period from September to June, which is a little more than the one used in the unburned area.

ACKNOWLEDGMENTS

I feel obliged to thank Miss Margarita Arianoutsou, whose hard post-graduate work has offered the information concerning Greece.I want also to thank Miss S.Adamantiadou for her help during the preparation of the manuscript.Support of NATO(SRG-12) in collecting certain data contained in this paper is gratefully acknowledged.

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VERTEBRATE POST-FIRE SUCCESSION [1/]

William O. Wirtz, II [2/]

Small mammals in chaparral and grassland were studied 9-11 years post-fire, predators were studied pre- and post burn, and rodents and birds were studied post-burn. In burned grassland and chaparral there was 1) rapid recovery of burrowing rodents, 2) loss of some chaparral species, followed by slow reinvasion months later, and 3) an invasion of burned areas by species not normally present. Rodent diversity was essentially the same in chaparral one and 17 years post-burn. Burning may alter species composition, but it doesn't decrease diversity. Breeding bird diversity was greater in 1-year than in 17-year chaparral; species numbers were not significantly different, but numbers of individuals increased. Food habits of red-tailed hawks, great-horned owls, and coyotes did not change significantly post-burn, but raptor reproductive success declined.

Key words: vertebrate fire survival and post-fire succession; rodents, raptors, passerines, predator reproduction and foods; chaparral, grassland, southern California.

INTRODUCTION

Many of us, at least in this country, have grown up with the idea that forest fires are devastating to all in their path; that plants and animals are destroyed in great numbers. Yet it is difficult to find much quantitative data on the effects of fire on animals, and there are conflicting reports as to the effects of fire on wildlife. A considerable amount of the literature on fire deals with its effects on plants and soil (c.f. Kozlowski and Ahlgren, eds., 1974). Few studies on the effects of fire on wildlife are quantitative, have adequate controls, or extend over a long enough period of time to assess the true effects of a particular fire on the local fauna (Bendell 1974). Of especial concern to us at this symposium is the fact that there are very little data on the effects of wildfire on wildlife in Mediterranean ecosystems. A notable exception is the work of Lawrence (1966), the current work of Ronald Quinn at California State Polytechnic University, Pomona, and the various studies I and my students have been engaged in in recent years at Pomona College. This paper will summarize some of the literature concerning the effects of fire on vertebrate populations and discuss some results of the ongoing studies at Pomona College.

CONDITIONS DURING FIRE IN MICROHABITATS UTILIZED BY VERTEBRATES

Lawrence (1966) placed thermocouples in various microhabitats in Sierra Nevada foothill chaparral during a control burn. Temperatures in surface humus and grass rose rapidly during the first 12 minutes to maxima of 354°C, while temperatues under a fallen oak log reached 560°C as the log was consumed. However, the maximum temperature reached under 5 cm of soil after 50 minutes was 69°C, and that 15 cm deep in a burrow was 72°C after 20 minutes. In a subsequent experiment, Lawrence (1966) found that all pinyon mice *Peromyscus truei* perished in blind burrows during an experimental fire, while voles *Microtus californicus* caged in open burrows at 15, 23, and 30 cm below the surface all survived. In this

1/ Presented at the Symposium on Environmental Consequences of Fire and Fuel Management in Mediterranean Ecosystems, Palo Alto, Calif., August 1-5, 1977.

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latter experiment the soil 15 cm below the surface heated to 59°C, while at 30 cm below the surface the temperature was less than 1°C above normal soil temperature.

Lawrence (1966) discusses the relationship between temperature, vapor pressure and relative humidity, reporting that at 22% RH the lethal temperature for rodents is between 59°C and 63°C and that above 60% RH it drops to 49°C; a vapor pressure below 40 mm Hg seems required for survival of small rodents in burrows. Apparently these conditions were met in his experiments with voles.

Tester (1965) reports that temperatures below soil surface during a control burn on Minnesota oak savanna did not exceed 59°C, and in most places were below 52°C, while litter temperatures ranged from 149°C to 204°C, and above soil temperatures ranged from 315°C to 399°C.

Howard *et al.* (1959) buried rodents at 5 to 18 cm in all metal Sherman traps prior to a control burn in California shrubland and reported that lethal temperatures were between 59°C and 63°C. Some traps apparently reached lethal temperatures even though buried 18 cm below the surface.

BEHAVIOR DURING FIRE AND SURVIVAL OF VERTEBRATES EXPOSED TO FIRE

The data presented above suggest that small vertebrates could survive fire beneath the soil, or perhaps in rocky outcroppings, providing that temperatures in these refugia did not exceed 59°C to 63°C. Lawrence (1966) adds that lowered relative humidity and vapor pressures below 40 mm Hg are probably also essential for survival. It is therefore relevant to consider information available concerning behavior of vertebrates during, and survival of vertebrates exposed to, fire.

Howard *et al.* (1959) report that four western rattlesnakes *Crotalus viridis* placed in open mesh squirrel traps in rock crevices survived a wildfire in mixed grass and shrubland in California. Kahn (1960) studied the effects of a chaparral burn on the western fence lizard *Sceloporus occidentalis*, and found reproduction in both burned and unburned areas the first spring post-fire. He found little difference in diet between burned and unburned areas, noted no movement from burned to unburned areas following fire, and felt that lizards survived the fire by retreating to burrows or seeking shelter under rocks. Lillywhite and North (1974) note that fire may temporarily increase the lizard carrying capacity of burned chaparral in southern California, and that lizards are not as abundant in older chaparral communities with dense foliage as in recently burned areas. Lillywhite (1977) found that the number of lizards of several species captured in old growth chaparral was significantly lower than that in post-fire chaparral, and Lillywhite *et al.* (1977) comment on the proclivity of western fence lizards *Sceloporus occidentalis* for perches on charred stalks of burned shrubs during the first two years post-burn.

Komarek (1969) provides numerous records of raptors and insect-feeding birds attracted to fires to feed on vertebrates and invertebrates fleeing the flames. Raptors are reported feeding over recently burned areas by Beck and Vogl (1972), Baker (1940), and Lillywhite *et al.* (1977). Howard *et al.* (1959) saw quail *Lophortyx californicus*, bushtits *Psaltriparus minimus* and a thrasher *Toxostoma sp.* leave a burn in California brushland, and reported at least five bird species feeding in the area during the burn.

Lawrence (1966) provides useful data on bird populations following a controlled burn in Sierra Nevada foothill chaparral. Breeding pair density was greater in burned chaparral and grassland than in unburned controls. Seed availability was greater post-fire, and recolonizer plants produced abundant seed. Insect numbers were also high and insects were more exposed to avian predation on burned areas. The net effect was that total numbers did not change significantly, but shifts in species composition were significant, and increased food availability seemed the major reason for avian success post-fire. An increase in raptor populations was also noted following the burn.

Howard *et al.* (1959) counted 321 quail *Lophortyx* and over 125 other birds at a spring on a burned area in California. Biswell *et al.* (1952) provide data on the carrying capacity of mature and treated chaparral for quail and mourning dove in California. Heavy brush and recent wildfire areas supported late summer populations of 100 California quail per square mile at elevations of 1500 to 2000 feet, while in opened brush densities reached 250 birds per square mile. Mountain quail *Oreortyx pictus* occurred at densities of 50-80 per square mile in heavy brush and recent wildfire areas at elevations of 1500 to 2000 feet, while opened brush supported populations of up to 140 birds per square mile. Mourning dove *Zenaidura macroura* populations were lowest in dense brush, higher in recent wildfire areas, and highest in opened brush.

A greater amount of information is available concerning the effects of fire on mammal populations, but as with other vertebrate classes, little of it deals with Mediterranean ecosystems.

Howard *et al.* (1959) saw woodrats *Neotoma*, gray squirrels *Sciurus*, and a bobcat *Lynx rufus*, leaving burning brush in California, but found no animals that had been injured or killed by the fire, though pocket mice *Perognathus* and cottontails were seen on the burn during the fire. On the other hand, Chew *et al.* (1958) surveyed a 0.69 ha area of California chaparral postfire and found the bodies of 32 rodents, 9 cottontails, an opossum *Didelphis*, and a mule deer *Odocoileus hemionus*. Only the opossum, one cotton tail, and one rodent were charred; apparently the rest had died of asphyxiation or heat prostration.

Lillywhite (1977), studying the effects of conversion of chaparral to grassland in southern California, reported that rodent species diversity was highest for chaparral sites opened by fire, and that overall diversity and density were significantly higher in chaparral than in grass.

Biswell *et al.* (1952) found brush rabbit *Sylvilagus bachmani* densities to be greatest in heavy chaparral or islands of dense brush in wildfire areas or opened brush. Jack rabbits *Lepus californicus* occurred at highest density in opened brush, moderate density on recent wildfire areas, and lowest density in mature chaparral stands.

Lawrence (1966), working in Sierra Nevada foothill chaparral, found that some species declined post-fire while others increased; no species was totally eliminated, nor was there any apparent diminution of total life on a burn after plant growth resumed. No marked rodents were found on the burn or in adjacent unburned areas 32 days post-burn, but marked animals were trapped on the burn four months post-fire, indicating some survival of the resident population. Pinyon mice *Peromyscus truei* exhibited a reduction in mean body weight post-fire, due primarily to reduction in body fat reserves, and also had increased reproductive rates. Pinyon and California mice *P. californicus* seemed least able to maintain preburn numbers in chaparral following the fire, while deer mice *P. maniculatus*, pocket mice *Perognathus californicus*, and harvest mice *Reithrodontomys megalotis* increased in grassland areas.

Cook (1959) studied the effects of fire on a rodent population in grassland and shrubland (*Baccharis, Rhus diversiloba, Artemesia*) in northern California, and found no evidence of migration from burned to unburned area, concluding that recovery on the burn was limited more by available cover than by food supply. Harvest mice and California voles *Microtus californicus* disappeared from grassland following the burn, but repopulated the following summer and reached densities equal to or exceeding those on adjacent controls by the second year. Deer mice and house mice *Mus musculus* invaded the burned grassland postfire, deer mice occurred at higher densities on burn than on control, and house mice were not found on the control. Brushland species were essentially eliminated by the fire, harvest mice and voles appeared on the burn the following summer, but remained rare on the control, deer mice and pocket mice showed a preference for the burn, and California mice were virtually excluded from the burn. The transition from brush to grass on burned shrubland was accompanied by a general shift from brushland to grassland species of rodents.

RECENT RESEARCH IN THE SAN DIMAS EXPERIMENTAL FOREST

The remainder of this paper deals with recent research on the effects of fire on vertebrate populations in the San Dimas Experimental Forest, Pacific Southwest Forest and Range Experiment Station.

The Experimental Forest covers 6,885 ha of land in the San Gabriel Mountains of southern California approximately 45 km east of Los Angeles. Elevations on the Forest vary from 458 to 1,678 m (Hill 1963), and the topography is generally quite steep, the average slope of the land being 68% with nearly half of the slopes having angles greater than 70% (Bentley 1961). The Forest is dissected by several north-south drainages, and south-facing slopes are covered by chamise *Adenostoma fasciculatum* dominated chaparral, while more mesic environments support a mixed chaparral community of chamise, ceanothus *Ceanothus* spp., manzanita *Arctostaphylos* spp., mountain mahogany *Cercocarpus betuloides*, and scrub oak *Quercus dumosa*. Drier south-facing slopes have, in addition to chamise, black sage *Salvia mellifera* and buckwheat *Eriogonum fasciculatum*, while riparian vegetation includes evergreen oaks (*Quercus agrifolia, Q. chrysolepis,* and *Q. wislizenii*), and additional shrub species.

Considerable detail about the Forest is summarized by Mooney and Parsons (1973), and post-fire plant succession in the area has been described by Horton and Kraebel (1955), Hanes (1971), Patric and Hanes (1964), Hanes and Jones (1967), and Plumb (1961, 1963). Woodrats *Neotoma fuscipes* were studied in the

Experimental Forest by Horton and Wright (1944), and Wright and Horton (1951, 1953) provide a checklist of the vertebrates found there 1936 to 1953.

A detailed fire history of the Forest is provided by Mooney and Parsons (1973). Of special interest is the fact that 67% of the area was consumed by fire in 1919, 92% was lost in July 1960, and 23.5% was destroyed in November 1975. In March 1969 small mammal live-trap studies were begun on two small adjacent watersheds (0505 and 0506) to determine 1) the composition and density of rodent species in regenerating chaparral (0505) and 2) what changes in composition and density of rodent species had occurred in an adjacent watershed (0506) which had been converted to, and artificially maintained in, grassland following the 1960 fire. The original area sampled at 15 m intervals was 2.5 ha, split about evenly between the two watersheds. In March 1970 the area was enlarged to 3.34 ha, also split evenly between the two watersheds. Trapping continued on this project for 24 months, encompassing 10,260 trap-nights. In the fall of 1974 studies were initiated on predator populations, with efforts concentrated in a 780 ha area of the Bell watershed, and considerable data were collected on red-tailed hawks *Buteo jamaicensis*, great-horned owls *Bubo virginianus*, and coyotes *Canis latrans* in the ensuing two years.

The Village fire of November 1975 burned 1619 ha of the Experimental Forest, consuming grassland at the north end of the Bell watershed in the predator study area, dense chaparral north of the Bell watershed, and dense chaparral in the upper East Fork of San Dimas Canyon at the eastern edge of the Forest. In the spring of 1976 ecology students under my direction made preliminary studies of small mammals in burned chaparral in the upper East Fork of San Dimas Canyon (Sunset), unburned chaparral in the upper North Fork of San Dimas Canyon, burned grassland in the Bell watershed (Bell 1), and unburned grassland (0506). Bird surveys were conducted at Sunset, Bell 3 (unburned 17 year old chaparral), Bell 1, and 0506. During the summer of 1976 permanent study areas for birds and small mammals were established at Sunset (burned chaparral at 1280 m), Oak (burned chaparral at 975 m), Bell 3 (17 year old chaparral at 975 m), Bell 1 (burned grassland at 914 m), and 0506 (17 year old grassland at 914 m). Grids of 100 stations each at 15 m intervals were wet up in Bell 3, Oak and Sunset, and 50 stations 15 m apart were placed in Bell 1 and 0506. These grids and lines have been trapped at intervals of 1 - 3 months since, and all areas have been periodically surveyed for birds.

Live-trapping in burned and unburned habitats 4 - 6 months following the Village fire produced small mammals in both burned and control areas (table 1). Trapping success was lowest in burned chaparral, but also low in unburned chaparral, and highest in unburned grassland. Pacific kangaroo rats *Dipodomys agilis* were caught with nearly equal frequency in burned and unburned grassland, while constituting over half of all captures in unburned chaparral and over a quarter of captures in burned chaparral. California pocket mice *Perognathus californicus* were most common in burned chaparral and rare in grassland. Brush mice *Peromyscus boylii* occurred chiefly on chaparral plots, while woodrats (*Neotoma fuscipes* and *N. lepida*) were taken only in unburned habitats.

Table 1: Percent distribution of captures of rodent species in burned and unburned habitats, and percent trap success Mar.-May 1976.

Rodent species	Chaparral		Grassland	
	Brn	Unbrn	Brn	Unbrn
Pacific Kangaroo Rat	28.5	55.6	95.0	91.0
Calif. Pocket Mouse	42.8	16.7	3.3	1.5
Woodrats	0	11.0	0	3.0
Brush Mouse	28.5	16.7	1.7	0
Deer Mouse	0	0	0	4.5
Percent Trap Success	1.9	10.0	14.3	22.3

Burned and unburned grasslands were trapped in January 1977, 14 mo post-burn, and again in April 1977, 17 mo post-burn (table 2). Pacific kangaroo rats were caught with equal frequency in burned and unburned grassland in January, and were more abundant in unburned grassland in April. California pocket mice were found only in burned grassland, as were deer mice *Peromyscus maniculatus*, while brush mice were present in low numbers in burned and unburned grassland. Harvest mice *Reithrodontomys megalotis* were present in both areas, though more abundant in unburned grassland, while California voles *Microtus californicus* were not captured at all. Percent trap success was about equal in both areas.

Burned chaparral at 1280 m (Sunset) has been sampled 4 times, beginning 8 mo post-burn (table 2). Pacific kangaroo rats dominated captures for all periods, while California pocket mice decreased in occurrence. Woodrats occurred in low numbers beginning one year

Table 2: Percent distribution of captures of rodents in burned and unburned habitats, and percent trap success, July 1976 - July 1977.

Rodent species	Grassland, 914 m				Burned Chaparral, 975 m								
	Burned		Unburned										
	1/77	4/77	1/77	4/77	7/76	8/76	9/76	10/76	11/76	12/76	2/77	4/77	7/77
Pac. Kangaroo Rat	74.3	48.3	71.4	77.6	60.0	49.1	46.4	45.4	46.9	53.3	45.8	52.1	30.0
Calif. Pocket Mouse	15.4	18.3	0	0	20.0	43.8	50.0	43.2	43.8	31.7	20.9	22.9	37.5
Woodrats	0	3.3	5.7	1.7	0	0	0	0	0	0	0	0	2.5
Brush Mouse	5.1	6.7	14.3	8.6	0	0	0	0	0	0	0	0	0
Calif. Mouse	0	0	0	0	6.7	1.8	0	11.4	3.1	6.7	8.6	5.2	5.0
Deer Mouse	2.6	16.7	0	0	13.3	5.3	3.6	0	6.2	8.3	24.7	16.7	7.5
Harvest Mouse	2.6	6.7	8.6	12.1	0	0	0	0	0	0	0	1.0	2.5
Calif. Vole	0	0	0	0	0	0	0	0	0	0	0	2.1	15.0
% Trap Success	26.0	40.0	23.3	38.7	3.7	14.2	9.3	14.7	21.3	20.0	27.0	32.0	13.3

Rodent species	Burned Chaparral, 1280 m				17 year old Chaparral, 975 m							
	7/76	11/76	1/77	4/77	8/76	9/76	10/76	11/76	12/76	2/77	4/77	7/77
Pac. Kangaroo Rat	80.0	76.6	82.3	65.6	15.4	18.2	27.7	17.1	24.5	18.1	25.4	35.1
Calif. Pocket Mouse	20.0	6.4	2.0	0	15.4	50.0	44.6	61.4	47.7	48.6	46.2	20.4
Woodrats	0	10.6	3.9	6.9	69.2	27.3	23.4	15.7	12.8	6.9	14.9	20.4
Brush Mouse	0	0	0	0	0	0	4.3	5.7	15.1	20.8	7.5	13.0
Calif. Mouse	0	0	5.9	2.3	0	4.5	0	0	0	5.6	6.0	11.1
Deer Mouse	0	6.4	5.9	25.3	0	0	0	0	0	0	0	0
Harvest Mouse	0	0	0	0	0	0	0	0	0	0	0	0
Calif. Vole	0	0	0	0	0	0	0	0	0	0	0	0
% Trap Success	1.2	15.7	17.0	29.0	3.2	11.0	15.7	23.3	28.7	24.0	22.3	18.0

post-burn, as did deer mice and California mice *Peromyscus californicus*. Percent trap success has increased steadily since July 1976. The burned chaparral area at 975 m (Oak) has been trapped 9 times since July 1976, 8 mo post-burn (table 2). Pacific kangaroo rats and California pocket mice have been trapped in approximately equal numbers. California and brush mice have been present on the area in low, but variable, numbers since the inception of trapping. Woodrats, harvest mice, and California voles were first trapped on the area in the spring of 1977, 17 to 20 mo post-burn. Percent trap success at Oak increased in winter and spring, and declined in the warmer months.

A 17-year-old chaparral area (Bell 3) at 975 m was chosen to represent the control for these studies, having last burned in July 1960. Brush density in the area necessitated the cutting of trails for access in July 1976, and Bell 3 has been trapped 8 times since August 1976 (table 2). California pocket mice occur in greater numbers on the control than do Pacific kangaroo rats, and both brush and California mice are present in low, but variable, numbers,

with the former being consistently more abundant. Deer mice, harvest mice, and California voles have not been taken on the control. As with the burned chaparral area at 975 m (Oak), percent trap success increased in winter and spring and declined in warmer months.

Additional data on post-fire succession of small mammals are available from the data of Wirtz and Hoban mentioned in Wirtz (1974). It is relevant to the present discussion to consider the percent distribution by habitat of captures of rodents in grassland, ecotone, and chaparral at an interval 9 to 11 years following the destructive burn of July 1960 (table 3). Pacific kangaroo rats were caught with greatest frequency in grassland, while California pocket mice were most prevalent in chaparral. Woodrats (mostly *N. fuscipes*, but some *N. lepida*) were taken most often in chaparral, as were brush mice and California mice. Deer mice were most prevalent in ecotone, while being taken with approximately equal frequency in grassland and chaparral. Harvest mice and California voles were most prevalent in grassland. The presence of these species in the chaparral may be explained by the presence of patches of grass in the chaparral regrowth. Percent trap success was highest in ecotonal areas and lowest in chaparral.

Table 3: Percent distribution by habitat of captures of rodents in grassland, ecotone, and chaparral, and percent trap success, 9 - 11 years post-burn.

Rodent species	Grass	Eco	Chap
Pacific Kangaroo Rat	56.9	17.1	26.0
Calif. Pocket Mouse	18.4	18.8	62.8
Woodrats	25.6	21.1	53.3
Brush Mouse	5.2	15.8	78.9
California Mouse	14.7	6.9	78.4
Deer Mouse	22.0	53.0	25.0
Harvest Mouse	56.3	17.0	26.7
California Vole	67.2	14.9	17.9
Percent Trap Success	26.8	31.2	18.6

Bird life was surveyed at varying intervals on all study areas from March 1976 through July 1977. In this period 72 species representing 26 families were observed. Many species are represented by sightings of single individuals, some by spring and fall migrants, others by spring breeding species, and the remainder by residents. Detailed statistical treatment of all bird data is beyond the scope of this paper, but information on species occurrence on the various study areas (fig. 1) provides insight as to post-fire succession. Unburned chaparral had 22-27 species of birds during spring breeding seasons, principally sparrows (Fringillidae), wrens (Troglodytidae), quail (Phasianidae), and scrub jay *Aphelocoma coerulescens*, wrentit *Chamaea fasciata*, and thrasher *Toxostoma redivivum*. Species seen regularly overhead were white-throated swift *Aeronautes saxatalis*, mourning dove *Zenaidura macroura*, and red-tailed hawk *Buteo jamaicensis*, the latter nesting in riparian habitat of canyon bottoms. Only 10 species were recorded as breeding in the unburned chaparral, though more probably do. Burned chaparral at the same elevation (Oak) supported an equal number of species during the breeding season with little difference noted in species composition, and also 10 species noted as breeding. Burned chaparral at 1280 m (Sunset) had 23-27 species present during the breeding season, with 11 species observed breeding. Large numbers of lazuli bunting *Passerina amoena* and lesser numbers of lark sparrow *Chondestes grammacus*, black-chinned sparrow *Spizella atrogularis*, goldfinches *Spinus psaltria* and *S. lawrencei*, house finch *Carpodacus mexicanus*, and towhees *Pipilo fuscus* and *P. erythrophthalmus* were conspicuous members of the breeding community. Swallows (Hirundinidae) and flycatchers (Tyrannidae) were commonly seen in the area, but not proven to breed here. Species numbers were lowest, of all areas studied, at 1280 m in winter. Species composition was lower in grassland than in any chaparral habitat, and lowest in burned grassland, where only three species were known to breed. Sparrows, Bewick's wren *Thryomanes bewickii*, wrentit, scrub jay, mourning dove, and California quail *Lophortyx californicus* comprised the bulk of the grassland avifauna.

An increase in raptors following chaparral fire is reported by Lawrence (1966). Observational data on common raptors and ravens from July 1974 through July 1977 are reported here (fig. 2) to check for such a phenomenon following the Village fire of November 1975. Of those species with adequate data, only the raven shows an apparent post-fire increase in numbers, and both red-tailed hawk and great-horned owl show an apparent decrease, a point which is contradicted by the data subsequently presented under raptor breeding data.

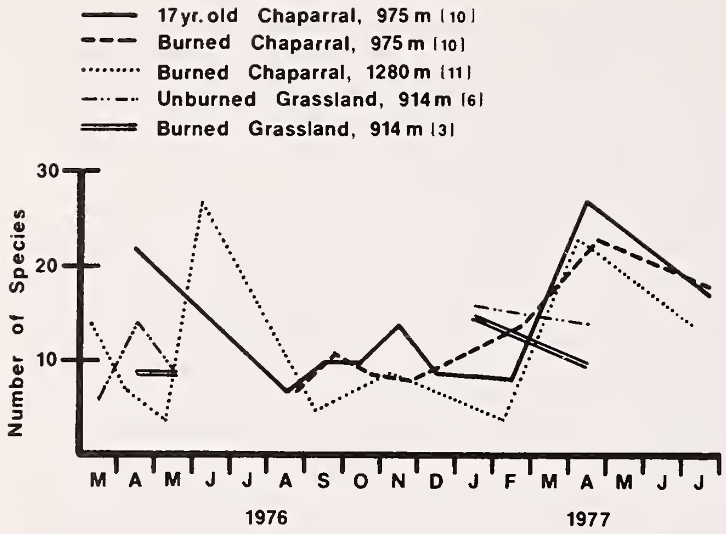

Figure 1. Species of birds present in burned and unburned habitats, March 1976-July 1977, and number [10] of species breeding in the spring of 1977.

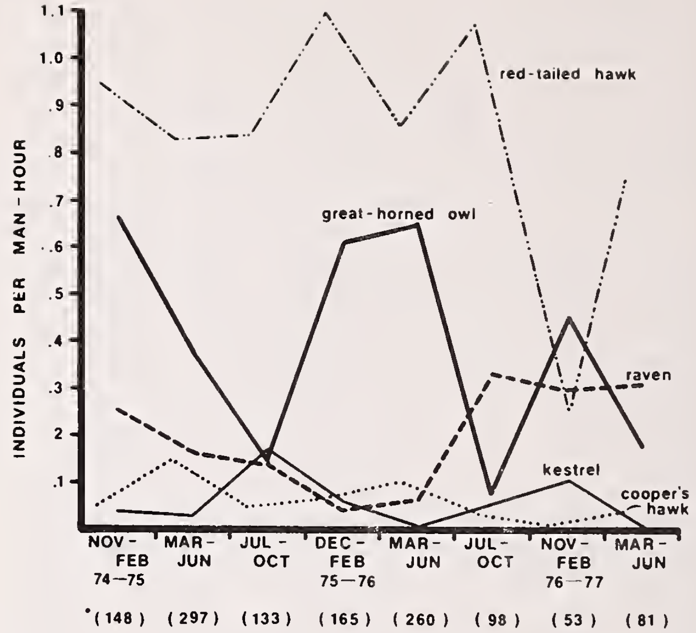

Figure 2. Presence of raptors and ravens Nov. 1974-June 1977, individuals per man-hour of observation, and total man-hours*.

Studies of predator populations concentrated on a 780 ha area of the Bell watershed from fall 1974 through summer 1976. Substantial information was collected on red-tailed hawks *Buteo jamaicensis*, great-horned owls *Bubo virginianus*, and coyotes *Canis latrans*, with casual observations on other species.

During 1975, red-tailed hawks had a density of 2.1 pairs per 260 ha in the study area. Five nests observed in 1975 produced an average of 3.2 eggs per nest and fledged 2.6 young per nest. Red-tailed hawk density during 1976 was also 2.1 pairs per 260 ha, but only 3 of the 1975 nests were occupied. One pair moved from their burned out 1975 site to an unburned area 0.4 km away and laid 2 eggs in a new nest, but the eggs disappeared within a week. The 3 nests observed produced an average of 2 eggs per nest and fledged 2 young per nest. In 1977 the area contained 2.0 pairs per 260 ha, but only 2 active nests could be found. One nest had a setting bird on 8 April, but was empty in early May. The second fledged 2 young. This latter nest is interesting because it was used each year; in 1975 it fledged 4 young, in 1976 only 3 young fledged, and in 1977 just 2 young fledged.

During 1975, great-horned owls had a density of 3 pairs per 260 ha on the study area. Five nests observed in 1975 produced an average of 2.2 eggs per nest and fledged 1.6 young per nest. One nest failed after the chicks hatched, and one nestling disappeared out of an exposed nest during a period of heavy rains. In 1976, at least 12 pairs of owls, plus 7 additional males, were located on the study area (4 pairs/260 ha), but no active nests could be found; none of the 1975 nests were used. In 1977, at least 9 pairs were located on the study area (3 pairs/260 ha), but only 2 nests were found. Both nests failed, one after eggs were laid, and the second when nestlings were at least half grown.

In 1975 four groups of coyotes used the general area studied, a total of perhaps 12 animals, but they certainly ranged off the study area. Young were produced by at least two of these groups in 1975, and by at least three of them in 1976.

Food habits of these three predators are summarized in figure 3, based on the analysis of 130 red-tailed hawk pellets, 289 great-horned owl pellets, and 590 coyote scats. Percent frequency of occurrence of red-tailed hawk food items was 36% California vole, 31% reptile (chiefly snake), 25% unidentified small mammal (mostly rodent), 25% insect, 20% woodrat, 20% rabbit, and smaller percentages of Beechey ground squirrel *Spermophilus beecheyi*, kangaroo rat, *Peromyscus* spp., harvest mouse, bird, and plant material. Similar data for great-horned owl are 63% woodrat, 38% California vole, 13% kangaroo rat, 13% insect, 12% rabbit, 6% pocket mouse, 6% plant material (perhaps accidentally ingested?), and lesser amounts of *Peromyscus* spp., harvest mouse, bird, reptile, and unidentified small mammal. Coyote food habits, based on frequency of occurrence, were 58% California vole, 51% fruit, 40% woodrat, 39% larger mammal (including deer, rabbit, and larger rodents), 19% insect, 11% mule deer, 10% rabbit, and lesser percentages of

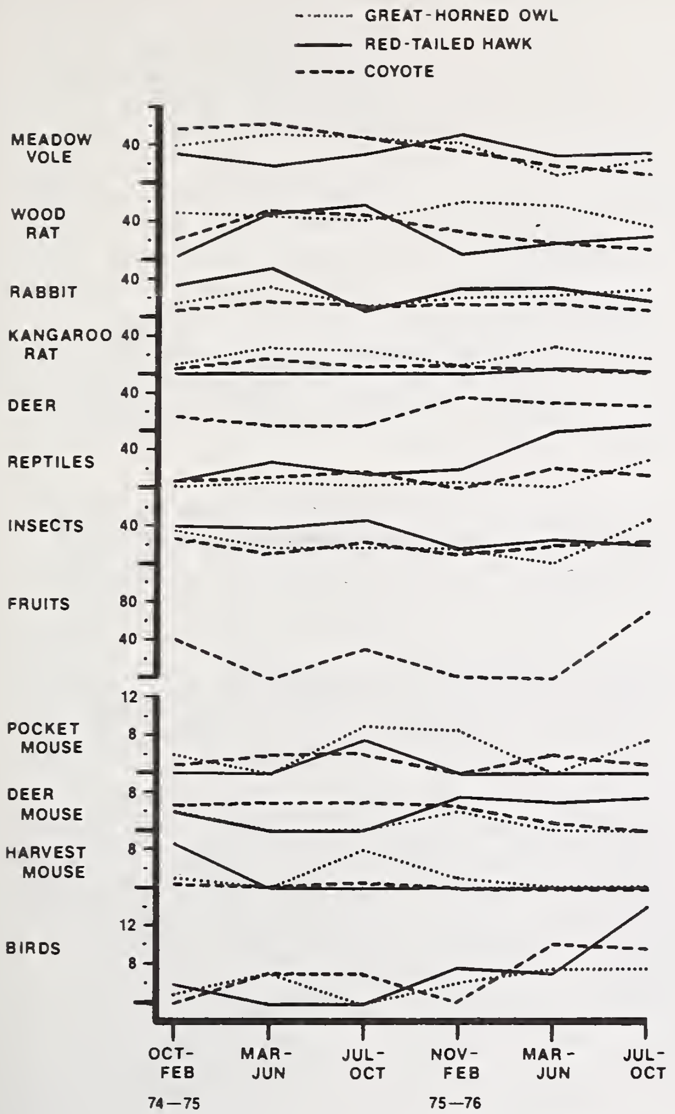

Figure 3. Percent frequency of occurrence of prey items in scats and pellets.

Beechey ground squirrel, pocket gopher *Thomomys bottae*, kangaroo rat, *Peromyscus* spp., pocket mouse, bird, and 1% trash.

The food habits data (fig. 3) may be examined for the effects of season and/or the 1975 fire on the diet of these three predators. Little effect of season on vertebrate foods taken can be observed. A post-fire increase in consumption of birds by all three species, reptiles by red-tailed hawks, and deer by coyotes, is noted. Fruit consumption by coyotes is much higher in winter 1976-77 than in two previous winters. Both harvest mouse and vole consumption by all three predators declines somewhat post-fire.

DISCUSSION

Recent data from the San Dimas Experimental Forest are still subject to Bendell's (1974) criticism of not extending over a long enough period to assess the true effects of a particular fire, but reports of on-going studies should serve to improve our understanding of vertebrate post-fire succession in chaparral.

The presence of three species of rodents in both burned grassland and chaparral 4 - 6 mo post-fire (table 1) supports the conclusions of others (c.f. Ahlgren 1966, Beck and Vogl 1972, Gashwiler 1959, Lawrence 1966, Tester 1965, Tevis 1956, and Vogl 1973) that small mammal populations are not decimated by fire in a variety of wooded habitats. Burrowing species, such as kangaroo rats and pocket mice, may have an advantage in survival (Lawrence 1966).

By the second spring following the Village fire more species were present in burned grassland than in unburned (table 2), California pocket mice and deer mice being found only on the burned area. Lawrence (1966) also observed an increase in pocket mice on burned grassland, and Williams (1955) found that deer mice appeared in greater numbers in relatively early successional stages after fire, lumbering, or mining in Colorado.

Trap success was equally low in 17-year old-chaparral, and burned chaparral at both 975 and 1280 m, 7 - 8 mo post-burn, but has climbed steadily since in all areas (table 2). Recovery seemed slower at 1280 m, where plant succession has been different from that occurring lower. Kangaroo rats are more abundant on burned areas, while pocket mice are most prevalent on unburned. Woodrats are common in unburned chaparral, and first appeared in burned chaparral at 975 m at 20 mo post-fire, and in burned chaparral at 1280 m at 12 mo post-fire. Brush mice have not been taken in burned chaparral, but are found regularly on the unburned area. California mice are captured irregularly in low numbers on the unburned area at 975 m, where they were first captured 7 mo post-burn. They are present in low numbers on the burn at 1280 m, but did not appear there until 15 mo post-burn. Deer mice, harvest mice, and California voles have not been taken in unburned chaparral. Deer mice are taken regularly on both burned areas, where they appeared 7 - 11 mo post-burn, and reached approximately 25% of total captures in spring 1977. Both harvest mice and voles first appeared on the burned area at 975 m 17 mo post-burn, and have not yet been taken on the burn at 1280 m.

Thus, in burned grassland and chaparral, we have seen 1) a rapid recovery of burrowing species like kangaroo rats and pocket mice, more of which may survive the burn; 2) a loss of some chaparral species, like woodrats, brush mouse, and California mouse, followed by slow reinvasion many months later; and 3) an invasion

of burned chaparral areas by species not normally found in mature chaparral, like deer mouse, harvest mouse, and California vole. Similar conclusions for brushland habitats have been reached by Cook (1959) and Lawrence (1966). An intriguing question remaining is: where does a species like the deer mouse come from post burn, and where are slow-recovery species like harvest mice, voles, and some *Peromyscus*, before they finally reappear post-burn? The Village fire burned over 8000ha; we can only assume that if we sampled a large enough area we'd find propagules of these species, and it would be very interesting to study post-fire movements of rodent species.

It may be instructive to examine rodent species diversity on all study areas as determined by Brillouin's (1956) information-theoretical measure of mean diversity per individual (figs. 4 and 5). Diversity in 17-year-old chaparral and 1-year-old burned chaparral at 975 m is essentially the same, while diversity in burned chaparral at 1280 m is slightly lower. Diversity in 10-year-old chaparral is greater than that in grassland of the same age (fig. 5), and diversity in 1-year-old burned grassland is somewhat higher than that in 17-year-old grassland (fig. 4). An interpretation of these data is that, while burning may alter the rodent species composition of chaparral habitat (tables 1, 2, and 3), it does not significantly decrease the diversity of the burned areas. While burned grassland may be more diverse than its unburned counterpart and rodent density may be even greater than chaparral of equal age, diversity of 10-year-old grassland is less than that of equal aged chaparral. Thus habitat alteration by conversion to grassland in southern California chaparral may be expected to decrease rodent species diversity, a conclusion also reached by Lillywhite (1977).

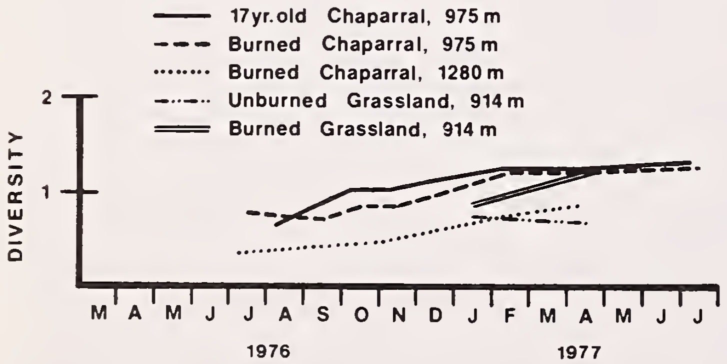

Figure 4. Rodent diversity in burned and unburned habitats, July 1976 - July 1977.

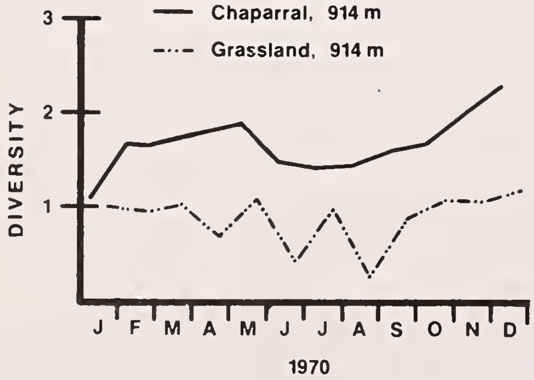

Figure 5. Rodent diversity in chaparral and grassland in 1970, 10 years post-burn.

The number of bird species present in 17-year-old-chaparral and the number found in burned areas at 975 and 1280 m was essentially the same for both breeding seasons studied (fig. 1). Subtle changes in relative abundance occurred. Some chaparral species, like scrub jay, wrentit, and brown towhee, occurred in lower relative numbers on burned areas, while others, such as bushtit and California thrasher, were not found at all. But rufous-sided towhee and Bewick's wren were more abundant on burned areas, and lazuli bunting, lark sparrow, and black-chinned sparrow clearly preferred burned chaparral at 1280 m. Birds specialized for taking insects on the wing, such as swallows, flycatchers, and swifts, were more abundant over burned chaparral, especially at 1280 m. These results essentially agree with those of Lawrence (1966), who found breeding pair density greater in burned chaparral than in unburned controls in Sierra Nevada foothills, and speculated that food availability in the form of seeds and insects was responsible for the observed changes. Quail occurred in roughly equal numbers on burned and unburned chaparral areas, agreeing with the observation of Biswell *et al.* (1952) that heavy brush and recently burned chaparral areas supported about equal quail populations in chamise chaparral of northern California.

The number of bird species present in burned and unburned grassland habitats was lower than that in all chaparral areas (fig. 1), and burned grassland had the lowest number of species, and the lowest number of breeding species, in two seasons studied. These results are at odds with those of Lawrence (1966), who reported high densities of breeding birds in burned Sierra Nevada foothill grassland as well. There may be differences in grassland plant diversity between the two areas that would explain these different results. Grassland in the Experimental Forest was seeded and artificially maintained following the 1960 fire, which might have affected plant species diversity compared to the area studied by Lawrence.

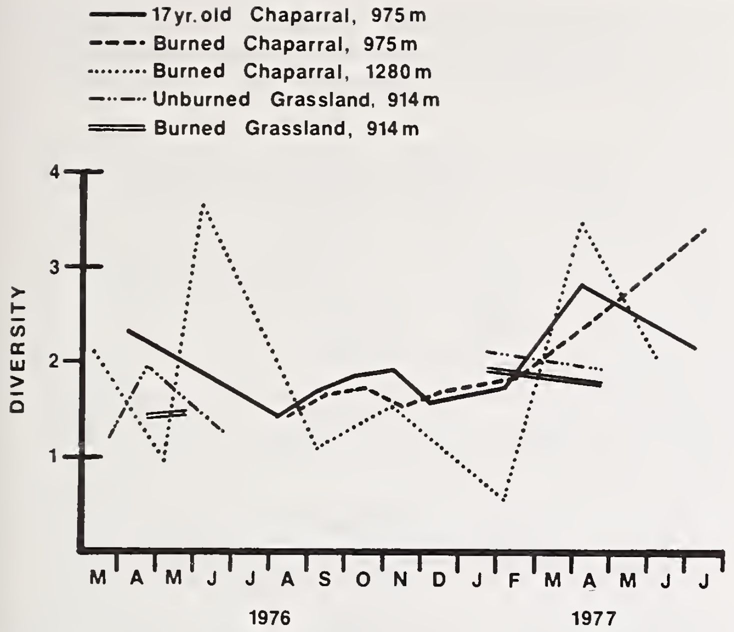

Figure 6: Bird diversity in burned and unburned habitats, March 1976 - July 1977.

Brillouin's (1956) diversity indices were also calculated for bird census data (fig. 6), and the form of this graph is very similar to that of numbers of species (fig. 1). However, the diversity index takes into account numbers of individuals, as well as numbers of species, present. Seasonal diversity patterns are similar in burned and unburned areas of both habitats, with diversity in grassland being lower than chaparral in both seasons. Diversity in burned chaparral is greater than in 17 year old chaparral during both breeding seasons. Though species number did not differ significantly between the two areas, numbers of individuals did, accounting for this difference in diversity indices.

Thus, chaparral fire may eliminate some species temporarily from post-fire seral stages, but most chaparral species can quickly reinvade burned habitats. Increased seed and insect availability, as postulated by Lawrence (1966), apparently permits burned habitats to support a greater number of individuals of chaparral species, and also attracts species not normally found in chaparral, resulting in increased diversity on recently burned areas. Grassland on the Experimental Forest may have reduced plant species diversity, thus accounting for limited bird diversity in this habitat.

Observational data on common raptors and ravens (10 species of raptors are considered uncommon) were examined for evidence of post fire increase in numbers, as has been reported by Lawrence (1966) for chaparral. Only ravens increased in frequency of occurrence post-fire. As scavengers and predators on invertebrates and small vertebrates, they may find food availability greater in recently burned areas.

Red-tailed hawk and great-horned owl densities were among the highest reported for North America in 1975 (c.f. Baumgartner 1938, 1939, Fitch 1940, 1947, Fitch *et al.* 1946, Hagar 1957, Luttich *et al.* 1971, and Orians and Kuhlman 1956), and reproductive success was also high. In two seasons post-fire densities remained high, or increased, but reproductive success decreased. Red-tailed hawks are reported to still have normal reproductive success in North America (Henny and Wright 1969), while great-horned owls may exhibit reproductive cycle fluctuations in response to prey availability (Rusch *et al.* 1972). There were two separate extenuating circumstances preceeding the 1976 breeding season; a severe drought and an extensive fire, and the drought continued in 1977. Major shifts in raptor diets were not noted post-fire (fig. 3), and it is assumed that adequate feeding areas remained in unburned habitat after the fire. However, destruction of habitat may have concentrated birds in parts of the study area which did not burn, as suggested by an increase in great-horned owls, resulting in overexploitation of food resources and dampening of reproductive effort.

Red-tailed hawks feed heavily on voles, reptiles, insects, woodrats, and rabbits. A post-fire increase in reptile consumption may be explained by increased vulnerability of reptiles, which are not seriously affected by fire (c.f. Howard *et al.* 1959, Kahn 1960, Lillywhite 1977, and Lillywhite *et al.* 1977), on the burned area. Great-horned owls take large numbers of woodrats and voles, and lesser numbers of kangaroo rats, insects, and rabbits. No significant shifts in mammalian predation post-fire were noted for this species. Coyotes feed heavily on voles also, and on plant foods and woodrats, and less frequently on deer, rabbits, and reptiles. An increase in deer consumption following the Village fire may be a result of reduced deer habitat carrying capacity post-burn, resulting in increased deer vulnerability to predation or higher mortality. Increased deer consumption may compensate for a decline in vole and woodrat consumption; this decline may be related to post-burn habitat alteration. Increased consumption of plant foods in the first summer post-burn may also reflect decreased rodent availability, or increased availability of fruit for fire-unrelated reasons. All species exhibit increased consumption of birds post-fire, which may be a result of increased vulnerability of this prey category in recently burned areas.

ACKNOWLEDGMENTS

The author is indebted to the Pacific

Southwest Forest and Range Experiment Station for financial support for all work since 1974, and to Raymond M. Rice and C. Eugene Conrad, former and present Project Leader, San Dimas Experimental Forest, for their tireless cooperation. Research funds from Pomona College supported the work 1969-71. Many present and former students have aided with field work, especially students of ecology in 1976. Special thanks are due to Therese L. Hoban for small mammal work 1969-71, Roland L. Redmond for raptor food habits and breeding biology, Sharon L. Booth for coyote food habits, data analysis and post-fire succession studies, C. Eric Orr for post-fire succession studies and raptor biology, and John A. Lubina for post-fire succession studies and data analysis. All figures are by Helen Wirtz, who also frequently participated in field work.

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EFFECTS OF FIRE ON PATHOGENS[1]

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Abstract: Fire can alter disease activity in forests and scrublands directly by affecting the survival and development of pathogens or indirectly by affecting those characteristics of plant communities, individual plants, or physical and microbial environments that influence pathogens. Few data are available to assess the ecological or economic impacts of such effects on diseases in Mediterranean ecosystems, but evidence suggests that some effects may have important implications in land management.

Key words: fire effects; plant pathology.

INTRODUCTION

Effects of fire on plant diseases in forest and scrubland ecosystems have received relatively scant attention, considering the possible implications of these effects. Of the many possible fire/disease interactions, few have been demonstrated by "hard" evidence, and even fewer have been studied sufficiently to permit estimation of ecological or economic impacts. Thus the available evidence--most of which has been summarized in recent papers by Alexander and Hawksworth (1975), Hardison (1976a, 1976b), Harvey et al. (1976), and Wicker and Leaphart (1976)--provides only limited material for discussion.

Discussion of fire and disease is complicated by the complexity of potential fire/disease interactions and the variability of fire itself. Effects of fire on diseases in a given stand will vary according to the timing and intensity of burning. Effects may be direct and rapidly manifested or they may be indirect and years removed from the event. They may involve simple, readily discernible changes such as the creation of infection courts, or they may involve complex chains of interactions among hosts, insects, microorganisms, and changes in the physical and chemical environment. To explore all such possibilities would be interesting but inappropriate here.

The following discussion emphasizes relatively uncomplicated interactions that are known or that can reasonably be assumed to occur. The literature search has not been exhaustive. Many observations on fire and disease involve brief, often unindexed mention within texts on other subject matter and are difficult to locate. Where lists of references are provided by previous reviewers, I have cited only the review paper, rather than repeat the list here. While many references deal with ecosystems other than Mediterrean, some of these have been cited to illustrate effects that might also occur in Mediterranean systems.

DIRECT EFFECTS OF FIRE ON PATHOGENS

Destruction Of Inoculum Or Food Base

Many plant pathogens carry over from year to year in dead plant parts. Burning such materials has long been used in agriculture to destroy inoculum and thereby prevent or reduce further infection (Hardison 1976a). In forests and scrublands, few observations on reduction of inoculum by fire are available.

In Finland, stump infection by *Fomes annosus* is reduced on burned areas (Kallio 1965). In southeastern United States, *F. annosus* infection is reduced in pine stands burned before thinning (Froelich and Dell 1967). Whether this is due to reduction of inoculum or to some other mechanism is unknown. *F. annosus* persists for many years in infected stumps and roots, and, under California conditions, most sporophores are produced in decaying stumps. Brown and Davis (1973) point out that fire often persists in and burns along decayed roots. Consumption of decayed stumps and roots by fire under Mediterranean conditions might reduce inoculum from sporophores or from mycelium in

[1] Presented at the Symposium on Environmental Consequences of Fire and Fuel Management in Mediterranean Ecosystems, Palo Alto, Calif., Aug. 1-5, 1977.

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roots, but definitive studies have not been made. In the Douglas fir region, similar burning does not remove inoculum of Poria weirii (Wallis 1976).

Burning stumps, snags, and down logs can decrease sporophore production by some decay fungi (Weir 1923). In at least one case, burning stimulates the production of sporophores of a decay fungus (Cribb and Cribb 1971). While few data are available for forests and scrublands in Mediterranean regions, it is reasonable to assume that fire destroys inoculum of most pathogens that sporulate on dead materials on the ground, provided fire intensity is sufficient to destroy the food base.

Damping-off fungi are often associated with duff and litter (Vaartaja 1952). Decay of seed by molds in duff and litter has been suggested to explain poor seedling emergence (Davidson 1971, Hartley et al. 1918). Damping-off can be reduced by burning duff and litter (Cooper 1965). It is likely that the often-observed success of seedlings on burned seed beds is due in large part to the removal of seed decay, damping-off, and seedling root rot fungi.

Fire may also reduce inoculum by burning all or parts of infected, live plants. Reduction of inoculum of Scirrhia acicola on long leaf pine seedlings provides a classic example (Croker and Boyer 1975, Maple 1976). Fire reportedly kills galls of fusiform rust (Cronartium fusiforme) on lower branches of southern pines (Siggers 1949) and presumably would have a similar effect on rusts common to Mediterranean ecosystems, e.g. western gall rust (Peridermium harknessii). Dwarf mistletoes in lower branches can be killed by fire (Roth 1974). Fire often destroys dwarf mistletoe-infected trees, owing to the accumulation of fuels in heavily infested stands and to the tendency for witches' brooms to provide "ladders" for fire to ascend and consume entire tree crowns.

Cantlon and Buel (1952) suggested that fire might reduce the prevalence of leafhopper vectors of blueberry stunt virus by destroying overwintering eggs in dead leaves. While data are lacking, any reduction in vector numbers following fire presumably would reduce the capacity of involved diseases to spread.

Inhibitions Or Stimulation Of Pathogens

Recently, Widden and Parkinson (1975) demonstrated that extracts from burned forest litter inhibit growth of some species of Penicillium and Trichoderma but not of Cylindrocarpon destructans, the only potential pathogen tested. Melching et al. (1974) and Parmeter and Uhrenholdt (1975, 1976) showed that materials in smoke inhibit spore germination and infection by a number of plant pathogens. Pyrolysis of woody materials produces numerous compounds (Hruza et al. 1974, Zavarin et al. 1963, 1965a, 1965b), including a variety of phenolic compounds. Deposition of such materials on plant surfaces or soil might affect a variety of microbial activities, but the possible significance of such effects in nature has not been evaluated.

Spore germination, growth, and fruiting of numerous fungi, mainly ascomycetes, are stimulated by heat or by materials produced by fire (Ahlgren 1974, Sussman and Halvorson 1966). The ecological functions of most of these fungi are unknown, but at least one pathogen, Rhizina undulata (a root pathogen of forest tree seedlings), characteristically attacks seedlings on burned areas, in part because spore germination is stimulated by heat (Hardison 1976a, 1976b, Harvey et al. 1976). This pathogen is not common to regions of Mediterranean climate.

Undoubtedly, many materials produced by burning have inhibitory or stimulatory effects, depending on a number of variables, including amount and kind of fuel, conditions of burning, quantities of chemicals produced, and conditions for deposition and retention of chemicals in soil or on plant parts. Because of this variability, generalizations regarding effects on complex microbial populations must often lack predictive value. Furthermore, when toxic materials do accompany heating of soil, they may be rapidly detoxified by soil microorganisms (Rovira and Bowen 1966, Zak 1971).

INDIRECT EFFECTS OF FIRE ON PATHOGENS

Effects Of Fire On Plant Communities

Fire, or its absence, can bring about dramatic changes in stand composition. Devastating fires may completely remove vegetation, leading to the establishment of dense, nearly pure stands of seral species, such as Douglas fir, ponderosa pine, or lodgepole pine. The inherent liability of pure stands to disease damage has long been recognized (Buchanan 1969, Hepting 1960). Undoubtedly, fire-induced initiation or perpetuation of stand purity can promote disease activity, as is often the case with dwarf mistletoes.

The fire ecology of dwarf mistletoes has been thoroughly discussed by Alexander and Hawksworth (1975) and Wicker and Leaphart

(1976). In nearly pure stands, dwarf mistletoe spread and intensification is relatively unimpeded. Where succession in the absence of fire might lead to the gradual conversion of such stands to mixtures less liable to damage, frequent light fires may prevent this succession. Periodic catastrophic fires result in the perpetuation of seral types in which survival of "islands" or individual trees infected with mistletoe often provides inoculum for infection of the new stand.

Pure stands are also liable to extensive damage from root diseases that spread readily from tree to tree where root systems are close or in contact. In California, *Verticicladiella wagenerii* in ponderosa pine is prevalent mainly where past fires have created dense, nearly pure stands (Goheen 1976). *Poria weirii* in Douglas fir and *F. annosus* in ponderosa pine are similarly associated with nearly pure stands. Since stands of Douglas fir and of ponderosa pine frequently arise following fire (Weaver 1974), fire is at least indirectly involved in creating stand conditions favorable to disease development.

Conversely, the absence of fire may lead to the establishment of stands inherently liable to disease damage. Partly as a result of fire exclusion, the open oak woodlands of Yosemite Valley have been replaced by dense, nearly pure stands of ponderosa pine that since have been damaged extensively by *F. annosus* (Felix *et al*. 1974).

Fire also may influence the prevalence of alternate hosts for rust fungi. Increases in numbers of oaks, alternate hosts for fusiform rust, has been attributed to fire exclusion (Czabator 1971). *Ribes* species, alternate hosts for white pine blister rust (*Cronartium ribicola*), increase following fire (Quick 1962). Considering the large numbers of host combinations for rust diseases (Arthur 1934, Boyce 1943), fire no doubt affects the prevalence of one or both hosts of many combinations that are found in Mediterranean ecosystems. Evaluation of the significance of such population changes will require field studies that have not as yet been made.

Finally, it should be noted that fire might interfere with the evolution of resistance to some diseases. Roth (1966) has suggested that, because dwarf mistletoe intensities sufficient to apply selection pressure for resistance also create fuel loads virtually insuring severe fire, resistant trees are apt to be destroyed before they can disseminate genes for resistance. The same might be true of root diseases that result in masses of dead snags and logs within centers of infection.

Effects On Individual Host Plants

Perhaps the best documented effects of fire on disease involve the creation of infection courts, especially for heart rot fungi (Harvey *et al*. 1976). Canker fungi may also be associated with fire scars (Hinds and Krebill 1975). Decay following fire scarring can reduce productivity in timber stands. It can also lead to hazard problems and to the loss of valuable specimen trees in parks and preserves, as may be the case with loss of giant Sequoias (Piirto 1977).

We have found that smoke can cause a variety of leaf injuries, and while we have no data on the possibility that such injuries serve as infection courts, similar injuries resulting from exposure to air pollutants do serve as infection courts for leaf pathogens (Manning *et al*. 1969, 1970).

Effects On Host Vigor

Fire can have two important and opposite effects on plant vigor. Following fire, trees may show reduced growth and vigor, owing mainly to heat injury (Hare 1961) or perhaps to "shock" if stand density is markedly changed. Such weakened trees are especially susceptible to canker diseases (Dearness and Hansbrough 1934, Scharpf 1975) and to insect attack (Hare 1961). Ecologically, numerous pathogens are adapted to attack weakened plants and can be expected to cause damage to weakened survivors following fire.

In the opposite direction, fire may lead to release of nutrients and reduction in competition, resulting in vigorous, succulent growth of survivors. The incidence of fusiform rust may increase on pines following burning (Siggers 1949). Yarwood (1969) observed an increase in powdery mildew (*Erysiphe chicoracearum*) on coyote brush (*Bacharis pilularis*) following fire. He noted similar increases in several diseases on several different hosts protected from competition by tillage. Although few data are available, it is likely that such diseases as rusts and powdery mildews often increase temporarily on lush foliage and shoots of post-fire sprouts and seedlings.

Effects On Physical And Microbial Environments

Changes in the structure and density of plant communities following fire can markedly effect local environments (Brown and Davis

1973). Air temperature, air movement, humidity, and insolation can be changed by fire-induced changes in ground cover. Since most pathogens are sensitive to these environmental factors, changes can be expected to modify disease activity. White pine blister rust provides a good example. Van Arsdel (1961) has demonstrated that the incidence of pine infection is influenced by changes in microclimate associated with the character of the ground cover. No doubt similar effects could be demonstrated for other pathogens common to Mediterranean climates, but data are wanting.

Effects of fire on physical and microbial characteristics of soil have been repeatedly documented and reviewed (Ahlgren 1974, Harvey et al. 1976, Jalaluddin 1969, Jorgensen and Hodges 1970, Murad 1972, Renbuss et al. 1973, Wicklow 1973) and will be discussed by other authors during this symposium. It should be sufficient here to point out that most soil-borne microorganisms, including pathogens, are sensitive to each other and to changes in soil pH, moisture, temperature, aeration, organic materials, and introduced chemicals. Fire-induced changes in any of these factors could affect pathogens or other microorganisms that in turn affect pathogens. That such interactions significantly affect disease activity in forest and scrubland ecosystems has not been demonstrated by substantial, quantitative field data, excepting the demonstrated effects on *Rhizina undulata*.

Other Considerations

The above discussion has emphasized post-fire effects. Brief mention should be made of possible pre-fire effects of diseases. As already noted, accumulation of fuels accompanies dwarf mistletoe and root rot activity in forest stands. Fires that might burn benignly through healthy stands are apt to burn with high intensity when they strike such fuel accumulations. Weaver (1974) has suggested that such uneven burning accounts for "the development of uneven-aged stands, comprised of even-aged groups of trees...."

Mutch (1970) has suggested that fire-dependent plant communities have evolved characteristics that make them highly inflammable at appropriate times during stand development. Biswell (1974) noted that as chamise (*Adenostema fasciculatum*) stands age, branch dieback increases, producing highly inflammable fuel accumulation. I have observed similar branch dieback in aging manzanita (*Arctostaphylos* spp.) fields. This manzanita dieback is regularly associated with a species of *Botryosphaera*, a canker fungus.

Many pathogens and insects are adapted to attack weakened plants. Scrubland fire types are adapted to periodic rejuvenation by fire (Biswell 1974). Following regeneration, stands of small, young sprouts have ample space and nutrients for growth, but as the plants enlarge, competition becomes a limiting factor. These observations suggest the hypothesis that, at some critical state in the development of fire-type scrublands, plants reach an age and size where competition leads to weakening and loss of vigor. Under such conditions, the activity of pathogens and insects may be triggered, thus producing fuel for the next rejuvenating fire. If this hypothesis is correct, then this "built-in" liability to disease and insect attack may be another inflammability strategy fitting Mutch's hypothesis.

CONCLUSIONS

In this brief review, I have tried to point out some of the probable or possible interactions among plants, pathogens, and fire as they might affect the development of plant communities. As pointed out by Hardison (1976b), it is surprising that so few data are available to evaluate the effects of fire on diseases in wildlands, considering that such data could have important bearing on fire management decisions in many types of plant communities.

With the possible exceptions of convincing data on decay following fire-scarring, the relationship of fire to dwarf mistletoe ecology, the reduction of damping-off following burning, and perhaps the association of some root diseases with dense, pure, post-fire stands of some tree species, there is little hard evidence that fire significantly affects the impact of diseases in plant communities exposed to or established following fires. And it is impact, not disease *per se*, that mainly concerns land managers.

Fire may reduce inoculum of some pathogens, at least temporarily, but unless burns are large, inoculum from surrounding, unburned areas may negate any significant effects, or rapid re-establishment of inoculum may minimize effects. Diseases such as powdery mildews may increase in scrublands following burning, but unless it can be demonstrated that temporary elevation of mildew activity significantly affects subsequent development and productivity of the community, mildew is only of biological interest. While dramatic changes in soil microbial populations have been demonstrated after burning, populations generally return to pre-fire equilibrium within

a short time. With the exception of a temporary reduction in seed and seedling losses, it is difficult to assign significance to temporary changes in soil microbiology. These arguments can be extended to most of the possible fire/disease interactions.

There is a very real need to develop quantitative data on fire/disease interactions. Such a goal must necessarily involve long-term cooperation of fire ecologists and pathologists. In the absence of the development of data through such cooperation, we will continue to be tantalized by a fascinating but questionably useful array of possibilities and probabilities.

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FIRE'S EFFECT ON PHYSICAL AND CHEMICAL PROPERTIES OF CHAPARRAL SOILS[1/]

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Abstract: The available information on plant nutrients contained in chaparral plants, litter, and soil is summarized. These nutrients are rapidly recycled when subjected to high temperature during fire. Although some plant nutrients, such as Ca, Mg, and Na, are only released and deposited on the soil surface, others, such as nitrogen and potassium, are volatilized and lost. Soil temperatures during light, moderate, and intense fires were quantitatively related to losses in soil nitrogen and organic matter during burning. Changes in other soil properties including pH, exchange capacity, aggregation, and soil wettability are also related to fire.

Key words: Fire, burning chaparral, soil nutrient, water repellency.

INTRODUCTION

Fire has been involved in the evolution of chaparral in the United States, apparently on a regular basis, for many millenum. Fires still burn regularly over these chaparral areas either as wildfires or prescribed burns. Although prescribed burning has been used for managing chaparral areas for many years, it is receiving renewed interest as a fuel management tool. As such, a rotation burning system would reduce the large, continuous brushfields that pose a constant wildfire hazard.

The impact of burning on chaparral areas has been researched for the past decade. Pioneering research on the effects of fire on soil wettability has been in progress for more than 15 years and is recognized worldwide. In contrast, studies on nutrient cycling, as affected by chaparral fires, have only been actively pursued during the past 4 to 5 years. Even more recent is interest in the effect of chaparral fires on soil microorganisms. This paper describes current knowledge of the chaparral-soil resource, the effect of fire on the physical and chemical properties of chaparral soils, and soil heating during chaparral fires.

THE CHAPARRAL-SOIL ENVIRONMENT

Any discussion on the impact of fire on soils must first review the available information on plant productivity and nutrients along with any basic data on soil and litter. Also, the quantities of plant nutrients present in the plant canopy that are released and deposited on the soil surface during a fire are important. Sufficient information is becoming available to generally characterize the distribution of nutrients in plants, soils, and litter.

Soil and Litter Characteristics

Soils developed under chaparral vary considerably, depending upon the prevailing topography, geology, and climate. Most chaparral soils develop on steep slopes. Typical are soils found on the San Dimas Experimental

[1/] Presented at the Symposium on Environmental Consequences of Fire and Fuel Management in Mediterranean Ecosystems, Palo Alto, Calif. Aug 1-5, 1977.

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Forest in southern California, where more than 86% of the slopes are steeper than 55% grade (Bentley 1961). On these slopes soils are shallow, with 93% less than 1 m deep. Soil depth is not a good indicator of the hydrologically active portion of a watershed because highly weathered parent material often holds much water that can be tapped by the roots of chaparral plants (Krammes 1969).

A characteristic chaparral soil on steep slopes could be described as excessively drained, shallow, and coarse textured, with rocks and gravel throughout the profile (Crawford 1962). These soils have a weak, angular, blocky structure; the consistency is loose when dry and friable when moist. Soil reaction is neutral (at the surface) to slightly acid (at 0.6 m below). The soil surface is usually rocky, and more than 10% of the surface may be covered with rocks larger than 7.6 cm in diameter. Bulk densities vary from 1.04 gm/cm^3 at the surface to 1.79 gm/cm^3 in the underlying subsoil (Holzhey 1968). The amount of plant litter on the soil surface depends on the density of the vegetation, and can vary from 13,440 to 80,640 kg/ha (Nord and Countryman 1972) with yearly additions amounting to 0.6 to 5.94 metric tons/ha (Kittredge 1955).

On gentler slopes and flat areas, soils tend to be deeper and contain more clay (sometimes more than 20%). Higher clay contents tend to produce a strong blocky to subangular blocky structure, and soils acquire a hard consistency when dry and a firmness when wet. Fewer rocks and stones are in the soil on gentler slopes.

Less plant nutrients are usually found in chaparral soils than in agricultural soils, and it has been estimated that about three times more nitrogen, potassium, and phosphorus are contained in the upper 15 cm of an agricultural soil than in a chaparral soil (DeBano 1974). Nitrogen is most frequently the limiting nutrient under field conditions, and plants grow better when nitrogen fertilizers are used (Hellmers et al. 1955). When soil water is not limiting, plant growth can also be increased with phosphorus fertilizers. Although other plant nutrients may also be limiting, deficiencies have not been reported.

Site Productivity

The rate fuel accumulates on a site affects the likelihood of fire. Highly productive sites that accumulate biomass rapidly, and contain substantial amounts of standing dead fuel and litter, are more likely to burn than infertile sites having a sparser plant cover. Differences in soil properties, site fertility, species composition, and time since burning, influence the annual productivity and biomass on any particular site. A summary of data from several sources (Specht 1969, Sampson 1944, Nord and Countryman 1972, Green 1970, DeBano and Conrad in press, Bentley et al. 1971) reflect these site differences and show the total standing biomass of a mature chaparral stand varies between 25,000 and 118,000 kg/ha (table 1). These values include both live and dead parts, although older stands may contain a large proportion of dead material. For example, more than one-half of the 49,000 kg of biomass in a chamise-(*Adenostem fasciculatum*) chaparral stand was reported dead (Specht 1969). In a mountainmahogany (*Cercocarpus betuloides*) stand, 66% were reported dead (Green 1970).

In northern California, Sampson (1944) reported an average annual production for the first five years following fire in chamise-chaparral of 2,000 kg/ha; however, when averaged over the first eight years, the rate decreased to 1,500 kg/ha. In southern California, the production for chamise-chaparral following fire was less, with only 1,200 kg/ha produced yearly during the first five years and 1,000 kg/ha/yr during the first 10 years (Specht 1969). Annual biomass production by northern and southern California chaparral equals that reported for heath in southern Victoria, but exceeds mallee in southern Australia (Specht 1969). However, garrigue in France is more productive and may produce 4,000 kg/ha annually during the first 10 years after fire.

Table 1--Plant biomass contained in chaparral plants as reported by several investigators.

Source	Sampson (1944) No. Calif. Chamise-Chaparral		Specht (1969) So. Calif. Chamise-Chaparral	Bentley et al. (1971) No. Calif. Greenleaf Manzanita	Green (1970) Southern California Chamise	Manzanita	Mountain Mahogany	Scrub Oak	DeBano-Conrad (in press) So. Calif. Ceanothus Redshank.
	STANDING PLANT BIOMASS kg/ha								
Age									
1 yr	1,747	1,266	3,743						
8-9 yr	12,746	11,850	8,626						
Mature	31,438	30,979	49,091	34,720	66,080	72,800	107,520	118,720	30,400

Nutrient Distribution

The distribution of plant nutrients in a chaparral ecosystem is important because fire rapidly cycles these nutrients. In some cases, burning may cause considerable losses. Several investigators (Specht 1969, Sampson 1944, DeBano and Conrad in press) have found similar amounts of nitrogen, phosphorus, and potassium in the above ground biomass of mature chaparral (table 2). These studies show the above ground biomass contains (in kg/ha) 134 to 142 of N; between 10 to 16 of P; and 105 to 158 K. Calcium, magnesium, and sodium were varied more among the studies which may indicate large amounts in the soil. For example, plants containing high amounts of calcium reported by DeBano and Conrad (in press) were grown on calcareous soils.

The distribution of nutrients in different plant parts is particularly important because fire affects some parts more severely than others. We have studied the distribution of plant nutrients in live twigs < 0.64 cm, live branches > 0.64 cm, and dead branches and twigs. These size classes are considered important because both small live twigs and dead material are consumed during a fire, whereas the live stem material > 0.64 cm is only charred. The plant nutrients were concentrated in the small, actively growing twigs which contained (in kg/ha) 80 of N, 66.5 of K, 7.3 of P, 9.9 of Mg, 101.3 of Ca and 3.3 of Na (DeBano and Conrad in press). These quantities represent 60% of the N and K, 71% of the P, 53% of the Mg, 43% of Ca, and 39% of the Na in the live and dead standing biomass. The litter contained an additional (in kg/ha) 147 of N, 22 of P, 174 of K, 172 of Mg, 465 of Ca, and 16 of Na. Some of the nutrients in the litter, particularly nitrogen, are affected by burning (DeBano and Conrad in press).

Soil Nutrients

The quantities of plant nutrients contained in chaparral soils are highly variable, relatively infertile, and lower in nutrients than agricultural soils (DeBano 1974). For example, chaparral soils may contain 3,100 kg/ha of N, whereas agricultural soils may contain 21,000 kg/ha in the upper 15 cm. Nitrogen is most frequently the limiting nutrient, and plant growth can usually be increased with nitrogen

Table 2--Plant nutrients contained in chaparral plants as reported by several investigators.

Source	Sampson (1944)		Specht (1969)	DeBano-Conrad
	Chamise	Chaparral		(in press)
Nutrient		kg/ha		
Nitrogen				
8-10 yr			41	
Mature			142	134
Phosphorus				
8-10 yr	5.5	6.1	7	
Mature	13.7	15.8	10	10.3
Potassium				
8-10 yr	57.0	60.5	70	
Mature	140.1	158.0	105	113.3
Calcium				
8-10 yr	63.2	67.2	65	
Mature	155.8	222.0	85	233.7
Magnesium				
8-10 yr			18	
Mature			35	18.8
Sodium				
8-10 yr			15	
Mature			40	8.5

fertilizers (Hellmers et al. 1955), except on freshly burned areas (DeBano and Conrad 1974). The natural fertility of a site may be affected by species composition. For example, California scrub oak (Quercus dumosa) and hoaryleaf ceanothus (Ceanothus crassifolius) adds 56 kg/ha of nitrogen annually, whereas chamise depletes fertility nearly that amount (Zinke 1969). Chaparral whitethorn ceanothus (C. leucodermis) (Hellmers and Kelleher 1959), and buckbrush ceanothus (C. cuneatus)(Vlamis et al. 1958; Delwiche et al. 1965) fix nitrogen. Postfire leguminous herbs, such as Lotus and Lupinus, may also be important nitrogen fixers on chaparral sites (DeBano and Conrad, in press).

SOIL HEATING DURING CHAPARRAL FIRES

When the chaparral-soil environment is burned over by fire, a series of changes begin which may remain, in varying degrees, until the next fire. The impact of any particular fire on a chaparral soil depends upon the fire intensity and soil heating which, in turn, are affected by several soil and vegetation properties.

Basic Heat Flow Process

Characterizing thermal conductivity and heat transfer in soils during chaparral fires is difficult and complex because high temperatures and large temperature gradients prevail. Under these conditions, traditional diffusion type equations, which adequately describe heat flow in dry soils, are invalid because of convection and gaseous exchange phenomena. Also, heat transfer becomes even more complex if water is present because any model must also accommodate coupled soil moisture, heat, and vapor transport. When appreciable water is present in the soil, the temperature at any particular depth does not exceed 100°C until the water has been evaporated or moved into lower layers (Scotter 1970). The heating of moist soil under grass has been analyzed within the framework of the diffusion equation (Scotter 1970). This analysis did not account for moisture changes and fluxes associated with heat transfer. However, a subsequent analysis of Scotter's data, supplemented with subsequent laboratory data, was used to develop a more sophisticated model which coupled transfer of water, heat, and water vapor (Aston and Gill 1975). This model was used to calculate soil temperature profiles, moisture profiles, ground heat flux, and evaporation under simulated surface fire conditions.

Typical Soil Heat Pulses During Chaparral Fires

These theoretical models have not been used for describing heat flow in chaparral soils. Instead, we have summarized much data on heat pulses in soils, during both wildfires and prescribed burns (DeBano et al., in press) and combined this with data from other investigators (Sampson 1944, Bentley and Fenner 1958). This permitted us to define heat pulses that could be used for simulating different intensity fires in laboratory experiments. These heat pulses were designed to represent soil heating under intense, moderate, and light fires burning in a typical chaparral stand having a dry soil (figs. 1A, 1B, and 1C). These heat pulses will be used to discuss the effect of fire on soil chemical and physical properties. These temperature curves do not imply one burning intensity throughout a particular fire. Most likely all three soil heating conditions occur at different places. However, most of the area burned probably is subjected to an average heat pulse represented by one of the three intensities.

Factors Affecting Soil Heating

The three heating curves presented are for dry soils covered with a relatively thin litter layer. Fuel loading, fuel moisture, meteorological conditions, and several other variables also affect fire behavior and burning intensity. Although little quantitative data is available on heat fluxes emanating downward from a burning plant canopy, it has been estimated that only about 8% of the energy released by the burning canopy is absorbed and transmitted downward in the soil (DeBano 1974). Downward heat transfer is further complicated by ignition and combustion of organic matter on the soil surface and in the upper layers of mineral soil. Qualitatively, heat originating in the burning canopy impinges first on the litter layer, which may be totally or partially consumed. The litter layer can provide an insulating effect on soil heating even if it is reduced to an ash layer (Scholl 1975). Upon reaching the mineral soil surface, heat is transferred downward through the soil by conduction, convection, and vapor flux.

Although several soil properties affect the rate of heat transfer in soils, the most important is soil water. Because water has a high heat capacity, moist soil usually does not rise above 100°C until the water in any one layer has evaporated (DeBano et al. 1976). Water moves out of the soil relatively slowly and, consequently, soil heating is reduced. Other soil physical properties, such as texture, also affect heat transfer. For example, thermal diffusivity of quartz is about three times that of clay minerals. Organic matter has a lower

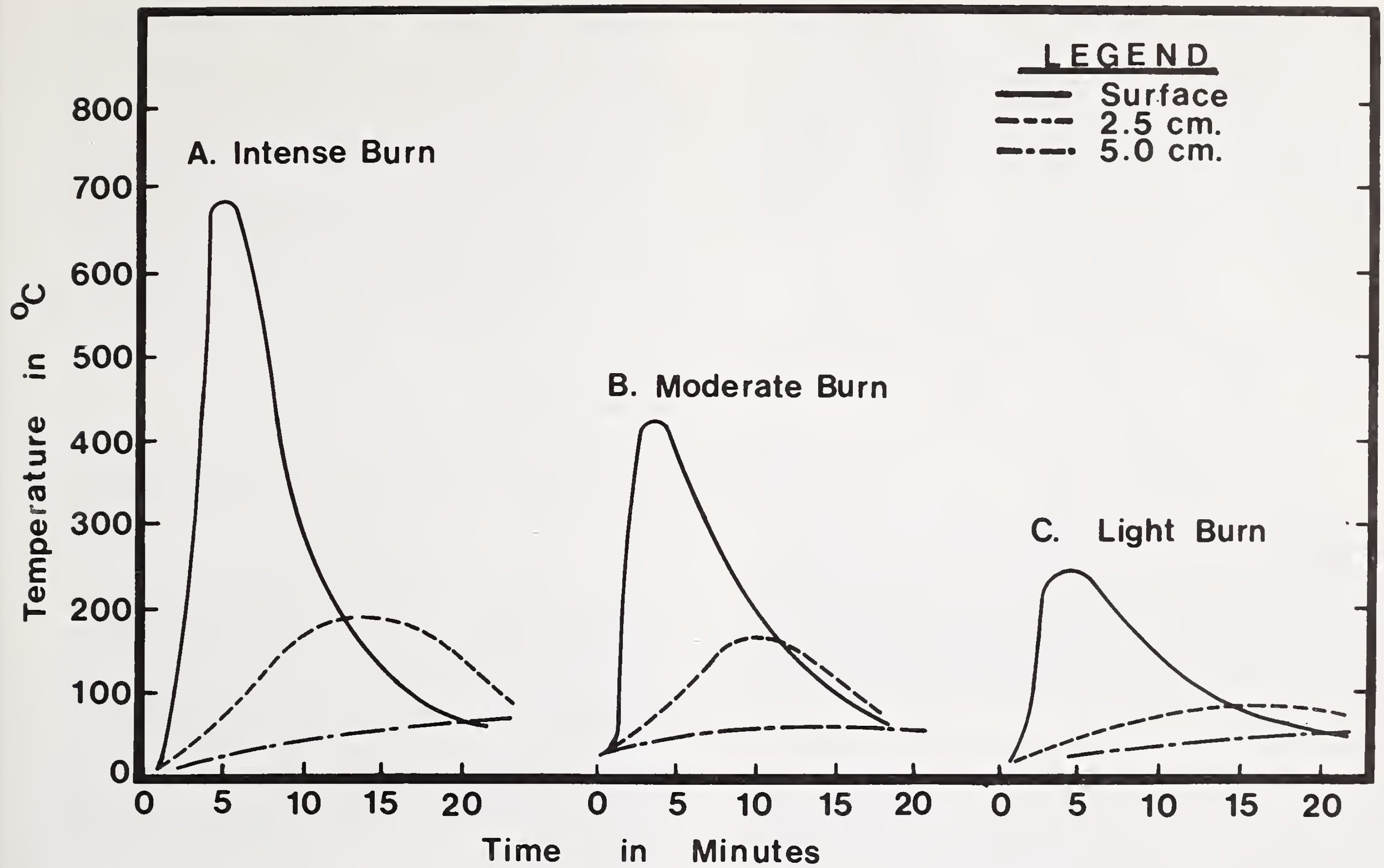

Figure 1--Typical temperatures at the surface and downward in the soil during a (A) intense, (B) moderate, and (C) light burn in chaparral.

thermal diffusivity than soil minerals but when ignited also heats the upper mineral soil layers.

SOIL CHEMICAL PROPERTIES

The effect of fire on soil chemical properties results primarily from changes in organic matter. The magnitude of change in both soil chemical properties and nutrient availability depends, to a large extent, on the amount of organic matter destroyed. The more obvious soil chemical properties changed by burning are pH, cation exchange capacity, nitrogen, sulfur, divalent ions, and potassium.

Soil Organic Matter

In addition to direct effects, fire alters organic matter so that decomposition rates during successional stages between fires are affected. Both these effects influence the resulting soil chemical properties.

Direct Effects

A burning experiment on organic matter (Hosking 1938) showed humic acids, which made up about 35% of the organic carbon in organic matter, were lost at temperatures below 100°C. At temperatures between 100°C and 200°C, nondestructive distillation of volatile organic substances occurred, and at temperatures between 200°C and 300°C, about 85% of the organic substances were destroyed by destructive distillation. When these relationships are related to the heat pulses present during intense, moderate, and light burns (figs. 1A, 1B, and 1C), an intense burn completely destroys all the organic matter at the soil surface. Maximum temperatures at the 2.5 cm depth during an intense burn are hot enough to destructively distill much of the organic matter. Moderately intense burns, where surface temperatures reach 432°C, are able to destroy most of the litter. Low intensity fires remove about 85% of the litter on the soil surface, but only the humic acids are altered at 2.5 cm depth.

Indirect Effects

The rate of litter decomposition after burning seems related to time since fire. A

recent series of laboratory and on site field measurements showed soil respiration, which was used as an indicator of decomposition, changes after burning. These studies showed respiration of litter collected from chaparral stands, that had not burned for 1, 15, and 54 years, decreased as time since burning increased. It was believed the major factor contributing to the slower decomposition rate in the older stands was the decreasing availability of nitrogen. Although the rate of organic carbon lost decreased since burning, soil respiration decreased in spite of the increase in available organic carbon.

Cation Exchange Capacity and pH

Organic matter has high cation exchange capacities (Buckman and Brady 1969) and may exceed those of clay particles. When organic matter is destroyed, these exchange sites are lost. Christensen and Muller (1975) found cation exchange capacity decreased and remained low for at least one year after burning chaparral soils.

Plant nutrients released from organic matter are highly soluble and, depending on the nature of the cations released, affect soil pH to various degrees. After burning, pH in chaparral soils is generally higher (Sampson 1944, Christensen and Muller 1975, Vogl and Schorr 1972), although the increase may be slight and may not affect plant growth (Sampson 1944). In contrast, fire increases pH in forest soils more than in chaparral because the forest litter and upper soil layers are more acid. Therefore, addition of soluble basic cations produces larger changes in pH. In contrast, the pH of a chaparral soil is likely to be only slightly acid or neutral, and adding soluble cations of Ca, Mg, and K may not significantly affect pH.

Nutrient Availability, Volatilization, and the "Ash-Bed" Effect

Nutrient Availability

Burning the surface litter and plant canopy releases large quantities of readily soluble plant nutrients such as nitrogen, phosphorus, potassium, calcium, magnesium, sodium, and probably sulfur. In this role, fire may be viewed as a rapid decomposer. Before fire, these elements are present in living and dead plant tissue and are unavailable for plant growth. Fire instantly converts these nutrients into readily available forms that can be used for plant growth, or if not, may be lost by postfire erosion (DeBano and Conrad 1976). The quantities of nutrients released depend on fire intensity and amount of combustible plant material available. Usually, large green stems are not consumed, even during the most intense fire, so not all nutrients in standing plants are released by fire. However, a large proportion of the plant nutrients present in the small plant twigs (< 0.64 cm in diameter) are released because they are almost totally consumed. Measurements taken before and after a prescribed burn showed the nutrient increases in the soil surface because of fire (in kg/ha) were: 9.3 for P, 44 for K, 62 for Mg, 136 for Ca, and 3.5 for Na (DeBano and Conrad, in press).

Volatilization

Although most nutrients are simply translocated from the burning canopy and litter layer to the soil surface during fire, some may be lost by volatilization. For example, total nitrogen on the soil surface was decreased 8 kg/ha by a prescribed burn (DeBano and Conrad in press). Large volatilization losses of nitrogen occurred during this fire, and it was estimated 146 kg/ha of N were lost from the site, of which, 101.3 kg/ha was lost from the standing plant biomass, 8.4 from the litter, and 36.4 from the upper 2 cm of soil. The 146 kg/ha of nitrogen lost from the site represented about 10% of the nitrogen contained in the plants, litter, and upper 10 cm of soil before the fire. Detailed information on the effect of fire on various nitrogen compounds is presented by Dunn and DeBano as a companion paper in this symposium. The study also suggested 49 kg/ha of potassium was lost--possibly by volatilization (DeBano and Conrad, in press).

Ash-bed Effect

High availability of nutrients following fire is one reason burned soils are reported more fertile than unburned soils. The increased fertility often leads to a lack of fertilizer response on burned watershed (Vlamis and Gowans 1961, DeBano and Conrad 1974). This stimulation in plant growth after fire is sometimes referred to as the "ash-bed" effect. In forest soils, plant response seems related to intensity of burning (Vlamis et al. 1955). Humphreys and Lambert (1965) found the "ash-bed" effect in a forest soil was due to higher pH and exchangeable cations and lower phosphorus adsorption capacity, exchangeable aluminum, and oxalate-soluble aluminum. No difference in loss on ignition, total nitrogen, ammonia nitrogen, total phosphorus, and exchangeable potassium, sodium, or magnesium could be found between the "ash-bed" soils and other soils. Better plant response was attributed to increased phosphorus availability. Although the "ash-bed" effect exists on burned chaparral soils, because fertilizer responses are lacking the first

year after fire, little is known about the effect of available nutrients on native plants being reestablished on burned chaparral areas.

The ash remaining after a forest fire may also inhibit some microorganisms and stimulate others (Widden and Parkinson 1975). Extracts of burned litter from pine forests can inhibit the growth and spore germination of many fungal species. This type of inhibition, coupled with some "heat shock" phenomena found in chaparral soils, makes the interaction between fire and microorganisms very complex. These relationships, along with the effect of fire on mineralization rates of organic matter, must be more fully understood before different burning intensities can be used intelligently in chaparral management programs.

SOIL PHYSICAL PROPERTIES

Soil physical properties are also affected by the organic matter destroyed during a fire. Aside from this, high temperatures (760°C) can alter the mineral soil particles near the surface. For example, irreversible changes in water of hydration of clays can occur at 980°C. The amount of clay in chaparral soils is usually small, so, this type of alteration is probably of minimal importance.

Organic matter acts as an aggregating substance in soils and is partially responsible for good soil structure. When organic matter is destroyed by fire, aggregation is destroyed, and some of the large pores, which improve water movement and aeration, are lost. Consequently, bulk density increases while air and water permeability decreases (Scott and Burgy 1956).

SOIL WETTABILITY

Much basic research has been done on the effect of burning on the wettability of chaparral soils. This work generally shows brush fires can decrease infiltration by producing a water-repellent soil layer (DeBano et al. 1967). On burned areas, a water-repellent layer is frequently found below and parallel to the soil surface. The soil at or near the surface may be wettable, but a layer of varying thickness below it repels water. Laboratory studies and field observations have permitted us to develop the following theory about how fire causes water repellency.

During the years between fires, decomposing plant parts containing hydrophobic substances accumulate in the upper part of the soil profile (fig. 2A). This layer corresponds roughly to the transition between the A_0 and A_1 soil horizons. If a water droplet is placed on a sample of soil from these horizons, it will

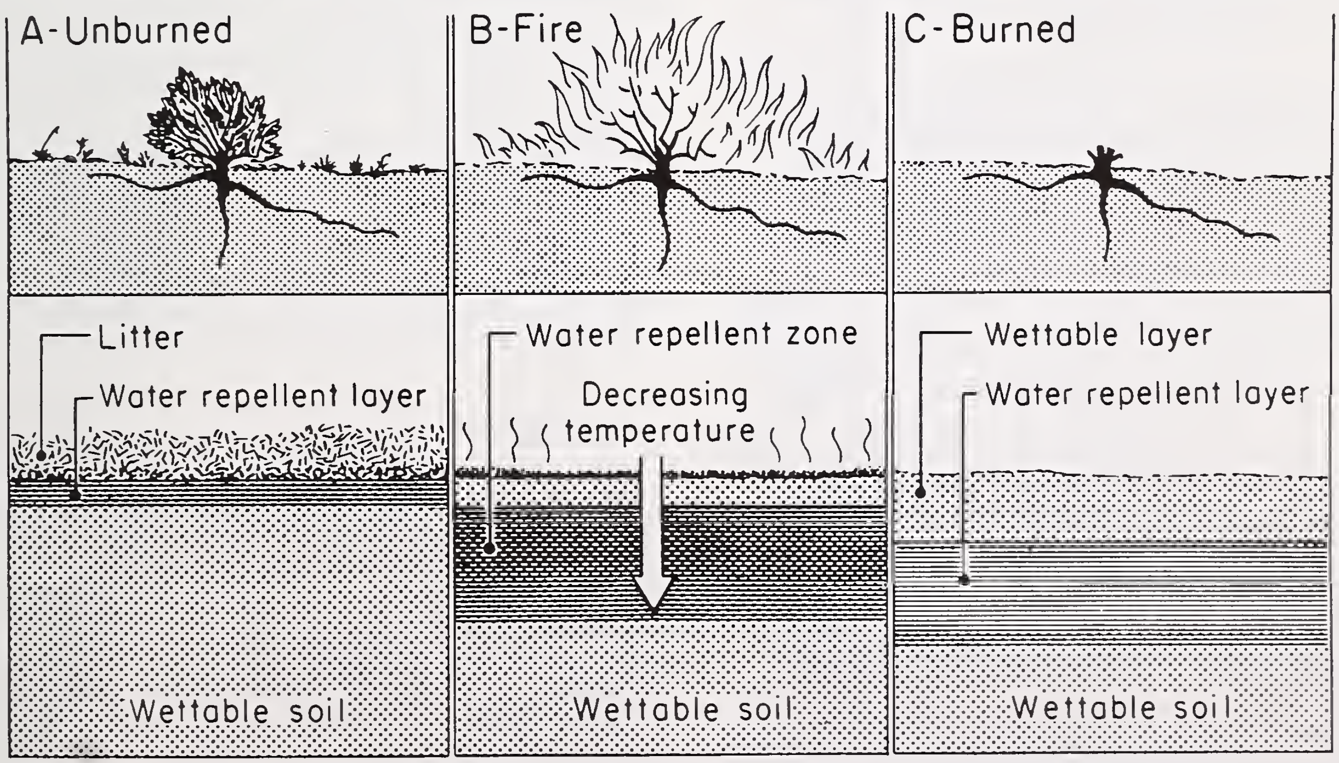

Figure 2--Water repellency before, during, and after fire. (A) Before fire, the hydrophobic substances accumulate in the litter and mineral soil immediately beneath it; (B) Fire burns the vegetation and litter, causing the hydrophobic substances to move downward along temperature gradients; (C) After fire a water repellent layer is located below and parallel to the soil surface on the burned area.

not penetrate immediately. Instead, it "balls up" and remains on the soil surface for some time before being absorbed. Although, in some cases, water repellency is severe enough to completely prohibit water absorption, it usually impedes absorption for a short time (DeBano et al. 1967). The most severe water repellency in unburned soil results when the soil particles are coated with partially decomposed plant parts intermixed with the mineral soil.

When fire occurs, it consumes the chaparral plants, the underlying litter layer, and may affect the organic matter in the mineral soil (fig. 2B). Heating may intensify water repellency in place below the soil surface by coating the soil particles more completely with hydrophobic substances. More important, however, are the large temperature gradients in the upper few centimeters of soil which cause vapor and gases containing hydrophobic substances to move downward in the soil profile, where they condense on soil particles (DeBano 1966). As indicated earlier, the soil surface can reach temperatures of about 700°C during an intense burn (extreme surface temperatures up to 843°C have been recorded). At 2.5 cm below the soil surface the maximum soil temperature may only be 190°C (fig. 1A). These large temperature gradients can move appreciable amounts of organic materials downward in the soil (DeBano et al. 1970). Some of these substances are hydrophobic and attach to mineral particles at various depths depending upon their polarity (Savage 1974).

After the fire has swept through an area, the soil possesses a water-repellent layer (fig. 2C). The thickness and depth of the water-repellent layer depends upon the intensity of the fire, the physical conditions of the soil, and the amounts of litter present. If the surface temperatures are not hot, such as during a light intensity burn (fig. 1C), the water repellency might be at or near the soil surface. In this case, it may only be a thin layer and of little hydrologic importance. If the fire is hot, as during an intense burn (fig. 1A), water repellency may be in deeper layers, and the surface could be wettable. Moderate intensity fire (fig. 1B) would produce an intermediate condition.

These water repellency relationships are not determined solely by intensity of fire; soil physical properties, litter thickness, and soil water content also affect the downward movement of hydrophobic substances. For example, sand and sandy loam soils may become more severely water repellent than finer-textured clay soils (DeBano et al. 1970). In the coarse-textured soil, the organic matter coats the soil particles more completely than it does in the finer-textured soils that have a larger amount of particle surface area. Also, when the soil is wet, hydrophobic substances tend to concentrate in a thin layer near the soil surface, as contrasted to a drier soil, where they move further downward in the soil (DeBano et al. 1976).

Water repellency can be present without fire; many areas throughout the world have a problem which is not related to fire but, instead, is induced by microorganisms (Bond 1960). The action of heat on these microbial decomposition products and undecomposed plant parts can intensify any water repellency present. It is this intensification by fire that has received the most attention during our studies in southern California chaparral.

SUMMARY AND CONCLUSIONS

The chaparral ecosystem is relatively poor in some plant nutrients, particularly nitrogen. A large proportion of all plant nutrients in chaparral ecosystems are contained in the small, actively growing plant stems, where they periodically suffer the full brunt of wildfires or prescribed burns. For most plant nutrients, this involves being released and deposited on the soil surface where they are readily taken up by plants or possibly lost by erosion. Nitrogen cycling is not this simple because nitrogen can be lost by volatilization. Although some nitrogen is lost, that remaining in the ash is highly available in the form of ammonia nitrogen, or after nitrification, as nitrate nitrogen. Consequently, nitrogen deficiencies are rare the first year after fire, which is misleading because its replenishment to the site is often ignored in the management of postfire succession. Any management plan not concerned with nitrogen fixation during the postfire years is likely to permanently and irreparably damage site fertility.

Plant nutrients contained in the litter and soil are also subjected to the same transformations occurring in the standing plants. However, the quantities of organic matter destroyed in the litter and soil are usually less than in the shrub canopy and appear related to burning intensity. Soil heating can vary depending upon whether the burn is intense or light. Sufficient soil and litter temperature data have been collected during chaparral fires to adequately characterize the type of heat pulses developing under light, moderate, and intense burning conditions. These temperature data can be utilized to estimate the magnitude of change, or loss occurring in organic matter, nitrogen, soil wettability, and other soil and litter properties. The impact of these temperature pulses on microorganisms and their

activities are less clearly understood, although we are currently quantifying these relationships.

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FIRE'S EFFECT ON BIOLOGICAL AND CHEMICAL PROPERTIES OF CHAPARRAL SOILS[1]

Paul H. Dunn[2] and Leonard F. DeBano[3]

Abstract: Microorganisms and nitrogen compounds in chaparral soils are sensitive to heating during fires. Maximum temperatures are important when evaluating changes in total nitrogen because 20 percent is lost at 211°C, 40 percent at 287°C, 60 percent at 422°C, and 80 percent at 528°C. Inorganic ammonia nitrogen starts being produced at 200°C, reaches a maximum at 300°C, and is completely volatilized at 500°C. Moist soils do not become as hot during fire as dry soils, and smaller thermal induced changes occur. Microbes are more sensitive to heating in wet soil than in dry soil, and duration of heating is an important consideration. Heterotrophic bacteria were the most heat-resistant of the microorganisms tested.

Key words: Fire, burning, soil microorganisms, nitrogen, bacteria, fungi, nitrogen fixation, soil water, nitrogen mineralization, ammonia, nitrates.

INTRODUCTION

Researchers at the Pacific Southwest Forest and Range Experiment Station have recently shifted their research emphasis from the physical and hydrological aspects of chaparral ecology to those concerned with soil nutrients and associated microbes. Understanding the chaparral nutrient cycle provides tools the land manager can use to manipulate chaparral growth and succession to achieve various management goals.

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The inevitable fate of chaparral vegetation is fire. When fire exclusion is practiced, fire danger increases with age of the chaparral, and it is more likely the stand will be consumed by a severe wildfire. Prescribed burning under less severe conditions provides another alternative to this type of management. The increased use of fire in chaparral management has stimulated research on the relationship of fire to soil nutrient cycling microbes. Much of this work has been concerned with the nitrogen cycle.

NITROGEN CYCLING

Nitrogen deserves special consideration because of its importance in the chaparral ecosystems. It is important for several reasons. First, it is the nutrient most likely to be limiting for plant growth (Hellmers, and others 1955). Second, it is easily volatilized by heating (Grier, 1975; White, and others, 1973). Third, direct chemical changes during soil heating and combustion transforms Nitrogen on the site into a highly available form readily available for plant growth or subsequent mineralization (Christensen, 1973). Finally, nitrogen is unique because it is replenished on a site after fire, mainly by nitrogen fixing organisms.

The amount of nitrogen lost during a fire depends on fire intensity and degree of soil heating. For example, 100 percent of the nitrogen in plant and litter material of pines was reported lost at temperatures above 500°C (White, and others. 1973) Heating from 400 to 500°C destroyed between 75 and 100 percent of the total nitrogen, and from 300 to 400°C between 50 and 75 percent was lost. At temperatures between 200 and 300°C, up to 50 percent of the nitrogen was lost. Below 200°C no measurable amounts of nitrogen were lost.

These nitrogen losses agree with those measured during a prescribed burn in California chaparral[4/]. In that study total nitrogen loss from the litter layer was linearly related to amount of organic matter destroyed. Little nitrogen was lost until about 25 percent of the organic matter in the litter was destroyed. When 70 percent of the organic matter was destroyed about 44 percent of the total nitrogen was lost. The maximum temperature of the litter under the most intense burning conditions was about 370°C. Additional burning experiments in our laboratory showed 20 percent of total nitrogen was lost when the average maximum litter temperature was 211°C. About 40 percent was destroyed at 287°C, 60 percent at 422°C, and 80 percent at 528°C.

The thermal decomposition of organic matter not only changes total nitrogen but also alters other forms of organic and inorganic nitrogen. Concentrations of both ammonia and nitrate nitrogen were higher in burned chaparral soils than in soils on comparable unburned sites (Christensen, 1973). Recently we have done several studies in our laboratory on the effect of burning on various forms of organic and inorganic nitrogen. In one of these studies we burned samples of a chaparral soil in a muffle furnace at temperatures of 100, 200, 250, 300, 350, and 500°C for 1 hour[5/]. After burning, the samples were analyzed for total nitrogen, inorganic ammonia and nitrate nitrogen, and amino acids (Bremner, 1965). The results showed total nitrogen started being lost at 200°C and decreased steadily until it was almost completely destroyed at 500°C (fig. 1).

In contrast, ammonia nitrogen began increasing at 100°C (fig. 1), the first sign of thermal decomposition (Russell, and others 1974). Above 200°C and up to 300°C, it

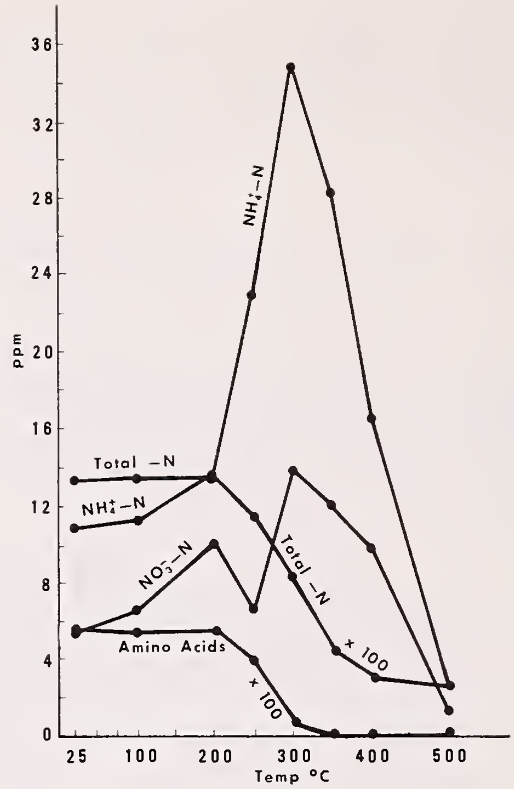


Figure 1--Changes in organic and inorganic nitrogen when heated in a muffle furnace at different temperatures for 1-hour.

increased dramatically and then decreased rapidly to below-prefire levels. Nitrate nitrogen did not increase as much as ammonia nitrogen and was completely destroyed at 500°C. All amino acids were lost at 350°C. In our laboratory, we confirmed that ammonia nitrogen is increased directly by fire and that nitrate nitrogen is not changed during the fire but increases substantially during subsequent mineralization.

The relationship between the changes in nitrogen studied for one-hour heating times (fig. 1) also holds for shorter burning times. Apparently maximum temperatures are more important than duration of heating when describing changes in nitrogen. For example, the same changes in nitrogen occurred for the same maximum temperatures during a laboratory burning experiment where heat pulses simulating wildfire conditions were applied to both wet (17 percent water) and dry (2 percent water) soil columns. Although both wet and dry soils showed similar nitrogen losses at a given temperature, the heat pulses developed were different. The water in the wet soil absorbed substantial amounts of heat before being evaporated and lost. Consequently the temperature at the 1-cm depth was much lower in the wet soil (380°C) than in the dry soil (480°C). In the wet soil the temperature at the 1.5-cm depth never exceeded 200°C whereas

4/ DeBano, L. F. and C.E. Conrad, unpublished data.

5/ Eberlein, Gary, unpublished data.

in the dry soil the 2.5-cm layer reached 200°C. The differences in soil heating are important because nitrogen begins changing at 200°C (fig. 1).

These differences in soil heating have also been observed in the soil temperatures measured during prescribed burns and wildfires (figs. 2, 3). At Mt. Palomar, in southern California, the water content of the litter and soil was 16-20 percent before the fire. Consequently the maximum temperature at 1-cm only reached 82°C (fig. 2). Very little change in nitrogen probably occurred at the 1-cm depth in this soil during the prescribed burn. In contrast, during a wildfire over a dry soil the maximum temperature at the 2.5-cm depth reached 174°C (fig. 3). At 1-cm it was probably much higher and substantially altered the nitrogen compounds.

Wildfires do not necessarily produce the most severe soil heating, although it is usually the case. For example, during an experimental burn at North Mountain, near Riverside, California, extreme soil heating occurred (fig. 4). On this site large amounts of live and dead fuel (66×10^3 to 112×10^3 kg/ha) were present (Green, 1970). The live fuel had been dessicated with cacodylic acid before the burn. During the fire the temperature at 2-cm exceeded 260°C for more than an hour. Undoubtedly a large amount of the nitrogen in the litter and upper 2-cm of soil was lost. Under a routine prescribed burning program this loss would probably be unacceptable.

MICROBIAL CONSIDERATION

Nitrogen Mineralization and Nitrification

The main way ammonia is produced in chaparral soils is by thermal decomposition as was discussed earlier. This makes the post-wildfire period the time of highest ammonia concentration, although total nitrogen is reduced by the fire. Another way ammonia is produced is by the decomposition of organic nitrogen compounds by microbial ammonification.

Ammonia production following fire seems to follow an increase in bacterial numbers. Also, the rate of ammonification depends on the intensity of fire and soil water content. In our laboratory, we found little ammonia was produced during incubation of a soil that had been burned intensely when dry. When a moist soil was burned intensely, less ammonia was produced directly during the fire but ammonia was made available by microbial ammonification of microorganisms and other organics killed during heating. Moderate burning over a moist soil does not change ammonia nitrogen in the soil or litter until sufficient time has elapsed to allow the bacteria to reestablish themselves and become active. We expected that the abundance of ammonia would provide a suitable environment for nitrification and that large active populations of Nitrosomonas and Nitrobacter group bacteria would flourish. The disturbance of the burn however, seemed to prevent these populations from recovering (Powlson, 1975). The nitrification that was occurring could be attributed to heterotrophic nitrification (Focht and Verstraete, 1977).

Nitrogen Loss

Nitrogen may be lost from the site after fire through several mechanisms. Denitrification has not been demonstrated in chaparral. It is doubtful whether anaerobic macrosites exist in the dry chaparral environment, although anaerobic microsites may allow limited denitrification (Focht and Verstraete, 1977; Keulen, 1975). Some ammonia volatilization may occur from the hot surface of a post-fire soil which may reach 79°C in midsummer (Veen, 1977). Ammonia is probably not lost by leaching because of limited rainfall (Ng 1974). Also, because it is a cation, it can be adsorbed on the cation exchange sites or may be irreversibly fixed into the lattice of the clay minerals (Veen, 1977).

Nitrogen Fixation

The large losses of nitrogen during each fire make regular replacement necessary. One such mechanism is by herbs, nodulated Lotus and Lupinus, which dominate chaparral sites immediately after a fire. For example, on Sunset Ridge in the San Dimas Experimental Forest, in southern California after a burn in 1975, Lupinus excubitus var. hallii was widespread. This perennial species continues to dominate the site 18 months after the fire. Nitrogen replacement is not always done by perennial species. At another site, in California's Angeles National Forest, an annual species of Lupinus dominated the first year after fire but by the second growing season it had disappeared. This condition illustrates how important rapid symbiotic nitrogen fixation by resident legume species is after fire. In an area near Santa Maria, California a nodulated Trifolium sp. was observed in addition to Lotus and Lupinus after prescribed burning. The legume species seem to occupy various microsites in post-burn chaparral areas but the pattern is not well understood.

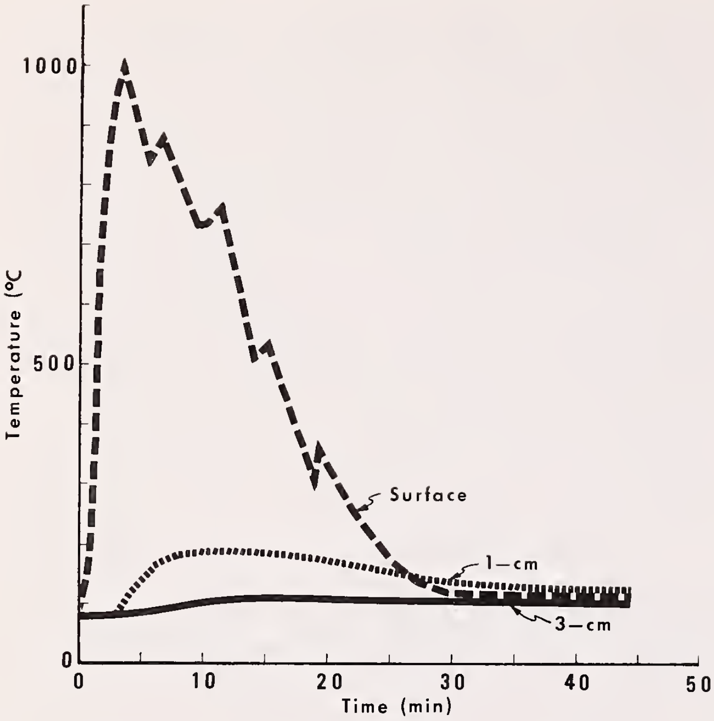


Figure 2--The heat pulse at the soil surface and downward in the soil during a prescribed fire at Mr. Palomar, California, May 1973. Soil water content was 16 percent.

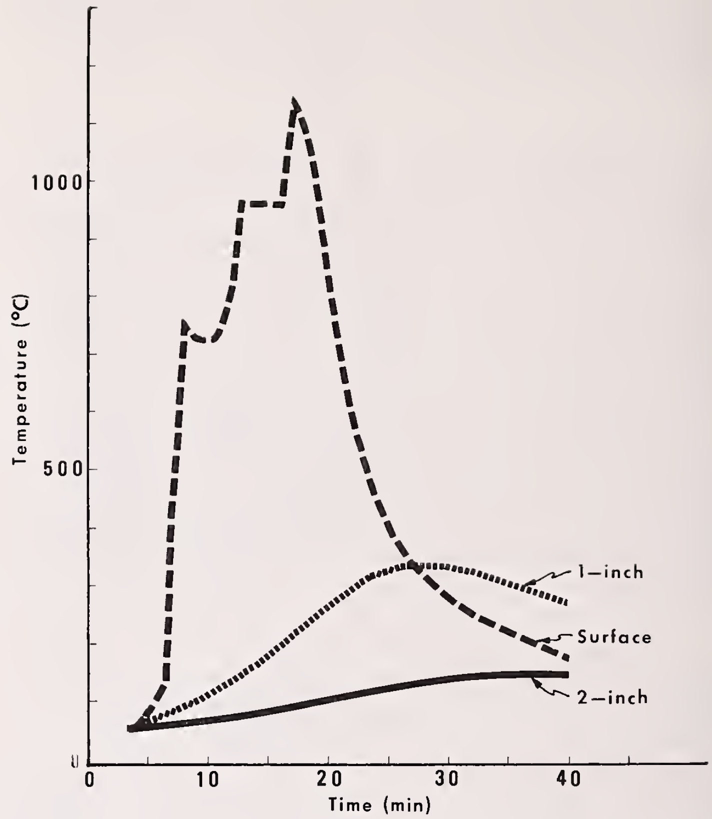


Figure 3--A heat pulse at the soil surface and downward in the soil during a wildfire at Lytle Creek in southern California, September 1968. Soil water content was 2-3 percent.

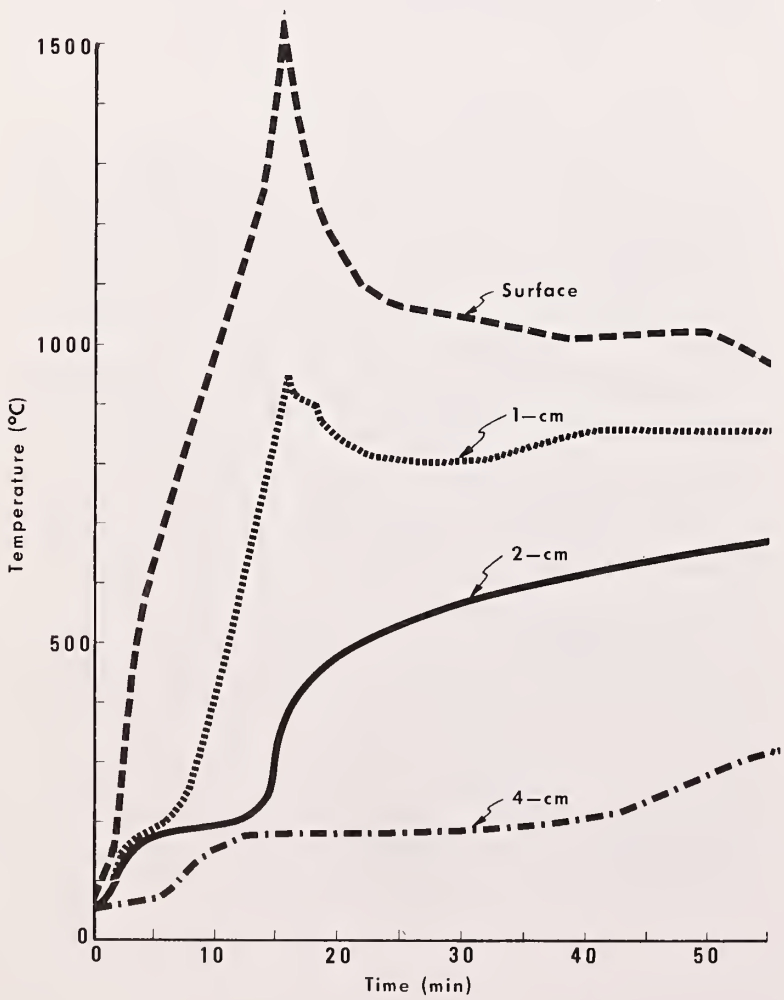


Figure 4--A heat pulse at the soil surface and downward in the soil during a prescribed fire at North Mountain, California, April 1970. Soil water content was 10-15 percent.

We have only measured fixation by the symbiotic nitrogen fixers Lupinus excubitus var. hallii at Sunset Ridge. On this site, by June of the first growing season, the roots were more than 1 m deep and 70 percent of the fixation occurred in the lower 70 cm of the root. Large nodules near the root crown, active earlier in the season, were no longer active. After 18 months the tap root resembled an elongated carrot, and both the secondary roots and fibrous end of the primary root were heavily nodulated.

A nonherbaceous nitrogen fixer in California chaparral is Ceanothus sp. This is an important symbiotic nitrogen fixing shrub in the Pacific Northwest (Youngberg and Wollum, 1976), but work by Jim Neel and Jochen Kummerow of San Diego State University, in San Diego County with Ceanothus greggii show few nodules are produced each year in mature stands. Preliminary estimates of fixation rates show Ceanothus greggii probably provides a quarter of its own nitrogen needs. All evidence to date indicates the first few years after fire is the time nitrogen replacement occurs, principally by legumes.

Free-living, nitrogen-fixing organisms may be another means of nitrogen replacement. Soil and litter samples collected from around the major species on the San Dimas Experimental Forest were tested for nitrogen fixation, but showed no activity under natural conditions. Some, however, developed the ability to fix nitrogen after incubating under warm, moist, light conditions for one week. The soil from around Coulter pine trees showed the most fixation. Testing throughout the season and at various times after fire is necessary before this can be fully evaluated. The amount fixed by these organisms is unknown.

Effect of Soil Heating on Microorganisms

The exact mechanism by which heating during fires kills soil microbes is unknown. Steam heating more effectively kills microbes than dry heating (Baker, 1970). The ability to endure heating has been attributed to many factors (Welker, 1976) of which thermostability of proteins and membrane lipids is considered most important. Water content of bacterial spores is also important and a moderately dry spore shows more heat resistance than extremely wet or dry spores (Murrell and Scott, 1966). Soil texture also seems to affect survival under heating, with better survival occurring in a heavy textured soil than in a sandy soil (Bitton, and others, 1976). The capsule of microorganisms do not seem to provide protection against death by heating (Bitton, and others, 1976).

Nitrifying Bacteria--We have studied the direct effects of fire over wet and dry soils on several soil microorganisms, including nitrifying bacteria, in the field and laboratory at the San Dimas Experimental Forest. Nitrosomonas and Nitrobacter group bacteria, important to the nitrogen cycle, are very sensitive to fire. In soil containing 2.5 percent water content, both groups started dying at 100°C and were completely destroyed by 140°C (figs. 5, 6) when the water content was 14.5 percent. The numbers in both groups were dropping at 50°C and were dead by 75°C in the case of Nitrosomonas group bacteria and 60°C in the case of Nitrobacter group bacteria. These groups do not recover quickly after a fire (Powlson, 1976).

Heterotrophic bacteria (including actinomycetes)--These microorganisms show a similar response to heating as the nitrifying bacteria but at different temperatures. In dry soil all bacteria were killed at 210°C (fig. 7) and most were killed above 150°C. In wet soil rapid kill begins after 50°C and all are killed by 110°C. The bacteria surviving at the high temperature in both cases were not necessarily spore forming genera (fig. 8). The actinomycetes, when considered separately from bacteria, were killed at 100°C in wet soil and 125°C in dry soil (fig. 9). Actinomycetes are generally considered more thermal resistant than bacteria (Bollen, 1969; Malowany and Newton, 1947), although this does not seem true for chaparral soil.

Fungi--Considerable research has been done on the effects of fire on fungi (Ahlgren and Ahlgren, 1965; Peterson, 1970; Wicklow, 1975; Widden and Parkinson, 1975). Most of this work has been on macrofungi. No consistent pattern of macrofungi has been observed to develop after fire. The only macrofungus observed after fire in chaparral is Pyronema omphalodes, which is frequently seen on the soil surface. Microfungi are not usually studied, but are important after fire in chaparral. For example, soils from the San Dimas Experimental Forest contain five species of fungi which are rarely, or never, seen unless the soil is heated. These are referred to as "heat shock" fungi. These species, in order of their frequency of isolation are: Aspergillus fischeri var., glaber Fennel and Raper, Humicola fuscoatra Traaen, Gelasinospora cercalis Dowding, Aspergillus fumigatus Freseninus, and Trichosphaeria sp.. Pyronema omphalodes (Bull. ex St. Amans)Fuck. is also present but not easily cultured. These heat shock fungi are isolated easily by heating agar plates of soil to 60°C for 1 hour. Although these fungi are poor competitors they can move quickly across areas sterilized

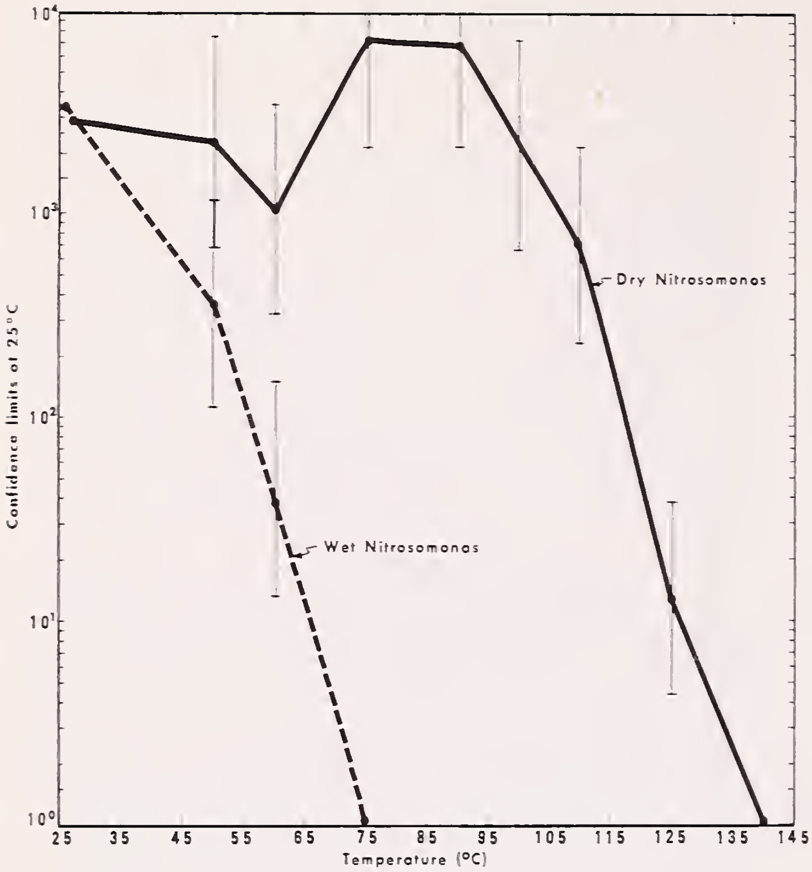


Figure 5--Survival of Nitrosomonas group bacteria in dry and moist chaparral soil subjected to various 30-minute heat treatments in an oil bath.

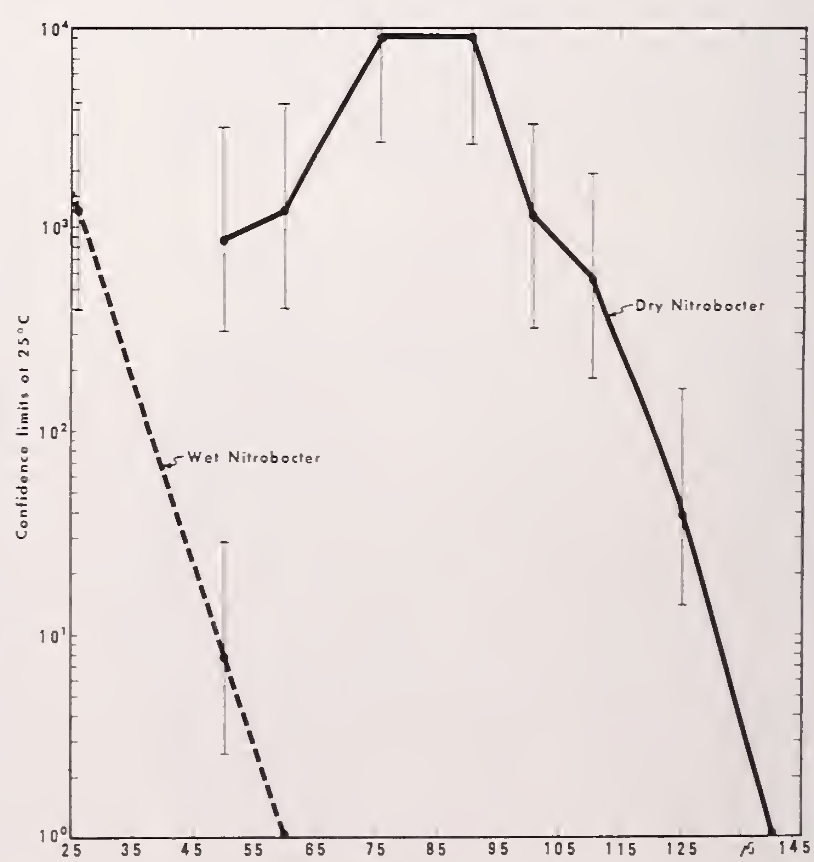


Figure 6--Survival of Nitrobacter group bacteria in dry and moist chaparral soil subjected to various 30-minute heat treatments in an oil bath.

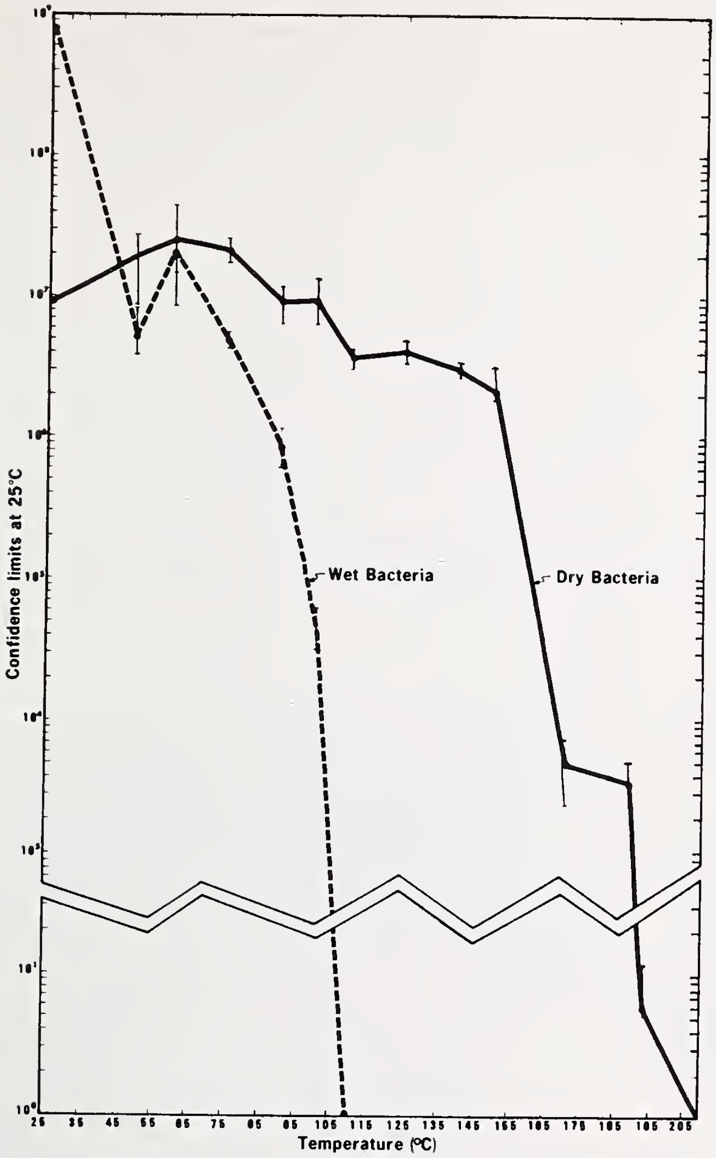


Figure 7--Survival of heterotrophic bacteria and actinomycetes in dry and moist chaparral soil subjected to various 30-minute heat treatments in an oil bath.

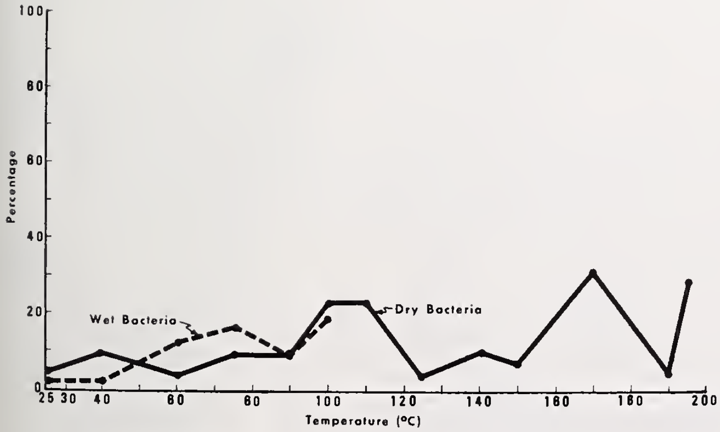


Figure 8--Percentage of bacteria colonies forming spores after various 30-minute oil bath heat treatments in moist and dry chaparral soil.

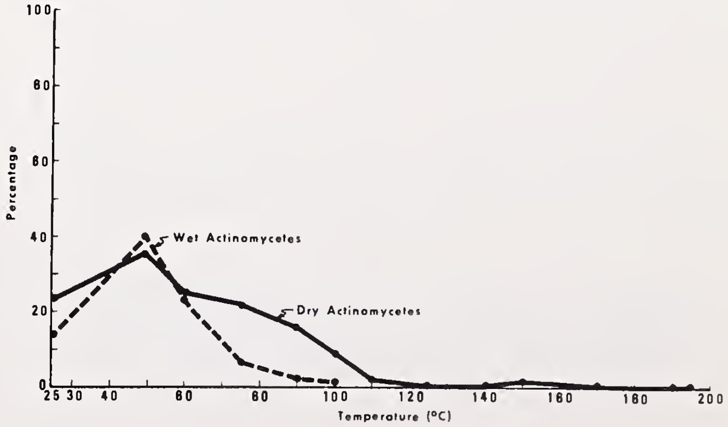


Figure 9--Survival of actinomycetes in dry and moist chaparral soil subjected to various 30-minute heat treatments in an oil bath.

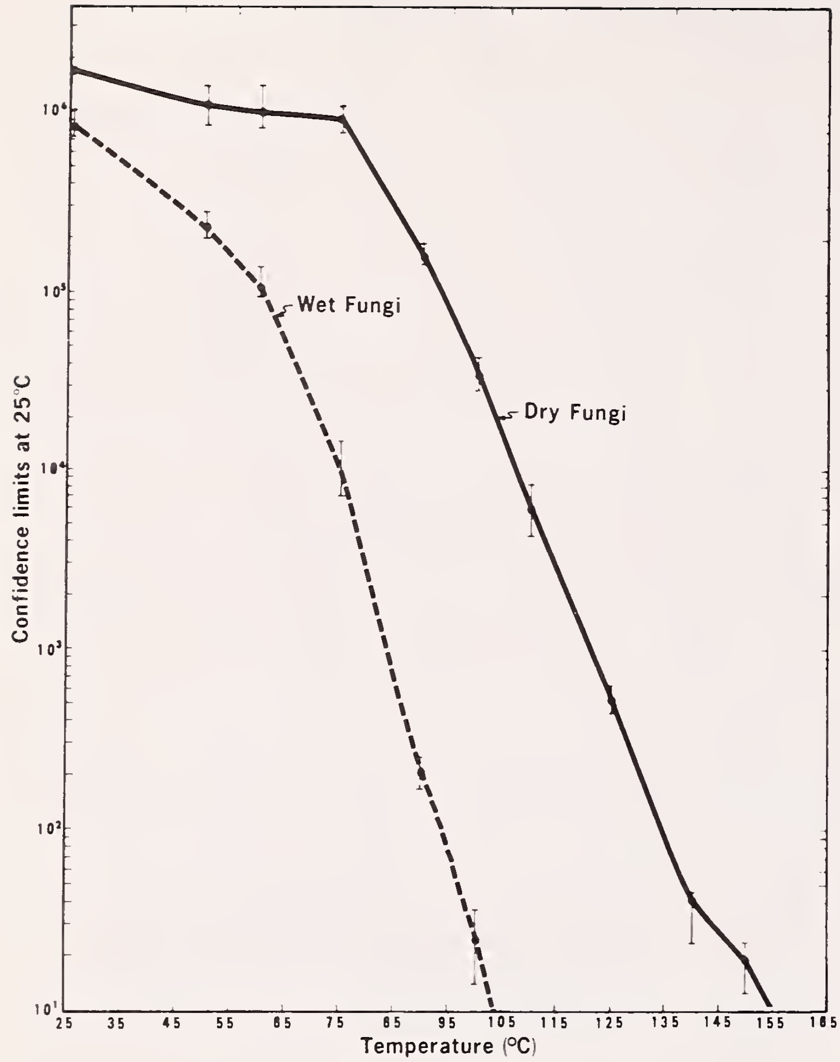
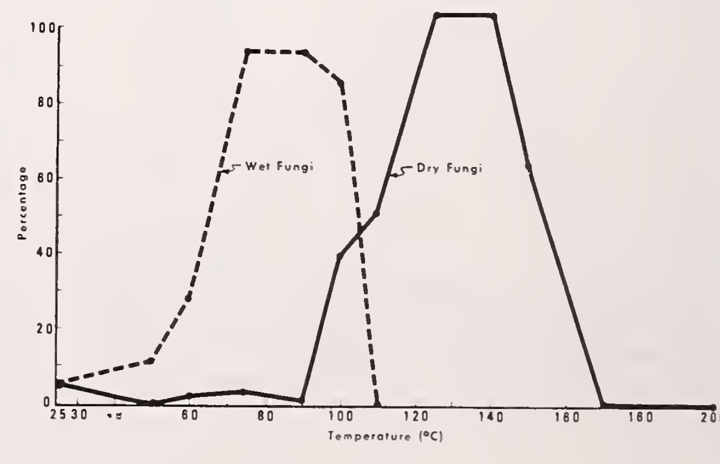


Figure 10--Survival of fungi in dry and moist chaparral soil subjected to various 30-minute heat treatments in an oil bath.

Figure 11--Aurvival of fungi in dry and moist chaparral soil as indicated by percentage of heat shock fungi.



by fire. They seem to follow an initial recolonization by bacteria. The slightly alkaline soil condition, which is common after fire, favors growth and reproduction of these fungi (El-Abyad and Webster, 1968 a,b). Heat shock fungi fruit in a succession following fire in grassland (Wicklow, 1975).

Fungi respond the same way to wet and dry heat as other microorganisms (fig. 10). Heating wet soil to 50°C reduces the numbers and 10% of the remaining are heat shock fungi (fig. 11). By 75°C most of the fungi are heat shock fungi and at 110°C all fungi are killed. In dry soil fungal numbers decrease rapidly after 75°C. The heat shock fungi start appearing at 90°C and are the only fungi left at 120-140°C where they also decline. At 155°C all fungi are killed in the dry soil.

SUMMARY

When chaparral management plans involve burning, three factors should be considered: First, prescribed burns during moist seasons will be cool and will volatilize the least amount of nitrogen from a site. Second, microorganisms are more sensitive to wet heat than dry heat. Thus far most burns in winter have been cooler, and the effects on microbes is about equal to that in most hot dry summer burns. It is possible, however, to produce an extremely hot burn over wet soil when certain burning conditions are present. Under these extreme conditions microbial numbers could be reduced to the extent that recovery is hampered. A third factor to consider in burning is seed viability and the viability of associated nitrogen fixing microbes.

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MINERAL CYCLING IN FIRE-TYPE ECOSYSTEMS[1/]

Paul J. Zinke[2/]

Abstract: This paper presents a review of the literature developing principles which apply to the mineral balance of fire-type ecosystems. Two examples of the effect of periodic fire on mineral balance from the author's research are presented, one a shifting cultivation example, and the other a 35-year history of the mineral cycle in a lysimeter planted to chamise that was burned midway through the thirty-year life of the chamise stand.

Key words: fire, fertility, shifting cultivation, calcium, magnesium, potassium.

INTRODUCTION

A fire type ecosystem such as chaparral or macchia has obvious relationships to mineral cycling. The ash bed left by the burning of such vegetation is striking evidence of mineral cycling. The period of the cycle of vegetation, fire, ash, vegetation regrowth, fire, is sometimes so short that any one of us may have seen several such periods in a given area. Sometimes the repetition in a given area is such the clumps of sprouting and regrowing vegetation will occupy the same positions as in past periods of the cycle, with similar patterns of ash beds occuring where these clumps had been each time burning occurs. This paper is concerned with the mineral cycling aspects of ecosystems subject to periodic ashing by fire and the attendant large periodic inputs of mineral elements to the soil. I will confine the paper to the immediate soil-vegetation-leaf litter-ash portions of the ecosystem; with a concentration on the major mineral elements.

I will cover these topics from the viewpoint of a literature review of mineral cycling, ash analyses of vegetation, species differences, effects of fire and ash additions to soil and on mineral cycling; and following the review, present some examples from my current research work involving periodic burning in shifting cultivation practices, and mineral cycling and soil storage of mineral elements in chaparral in California.

LITERATURE REVIEW

There is an extensive literature on the various aspects of mineral cycling between soil and vegetation that is relevant to fire type ecosystems. Much of this has been reviewed by Brown (1944), and where reference is made in this text to an author not cited in the Bibliography this is the source.

The origin of the literature on ash analyses is in the obvious fact that usually when vegetation is burned, ash is produced. Pliny in his natural history gives a review of experience prior to 77 A.D. made reference to the fact that fire concentrated the mineral matter of the vegetation in the ash. Since then, most of the principles which we have come to accept were developed after 1500.

1/Presented at the Symposium on Environmental Consequences of Fire and Fuel Management in Mediterranean Ecosystems, Palo Alto, Calif. Aug. 1-5, 1977.

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Plants contain mineral matter that was obtained from the soil and returned to the soil upon decay was stated by Palissey in 1563. Boyle noted in 1663 that there were various salts in the soil and that plant species differed in their up take of these. In 1674, Glauber defined the topic of this paper in describing the cyclical nature of the uptake of salts from the soil and their return, resulting in his concept of a perpetual "circulation of the elements". Francesco Redi noted in 1698 "The quantity of ash and of salts obtained from different plant materials will vary according to differences in species and in season of the year and locality in which plants are gathered". The interchangeability of some elements for each other in the nutrient cycle, such as potassium for sodium was observed by Duhamel in 1737, when he found that a species such as _Salsola kali_ which is normally high in sodium content on a saline soil, would be high in potassium on other soils. De Saussure (1804) was able to compile a considerable list of ash analyses of various plant species. Wiegman noted in 1842 that different plant species remained in similar rank relative to ash content when grown on soils such as sands and clays widely differing in mineral elements. During the period from 1830 to 1880, the yearly proceedings of the Tharandt Forest School published numerous analyses of forest trees, to further the understanding of the drain on site fertility created by harvesting forests. These analyses showed that for woody vegetation, the mineral constituents increased in concentration as the samples analyzed progressed from the lower stems to branches to twigs, and finally to foliage. Analyses of most the the species in the flora of France were published by Malaguti & Durocher (1858) in which they found that the same species growing on soils high in calcium had lowered contents of sodium and potassium. Fliche & Grandeau (1873) further elaborated this principle to include the concept that some species had lime induced deficiencies of other mineral elements, and later demonstrated that adding lime to soil might make it impossible to grow a species such as _Pinus pinaster_ on sites where it had grown before. Thus, successional changes related to soil chemical changes related to alterations in composition of minerals cycled was demonstrated. This substantiated earlier opinions of Liebig (1849) that succession from pine to oak would occur due to the ash returned to soil from fires in the pine forests of the southern U.S. . Hilgard (1880) further observed the evidence that agricultural clearings in the southern pine region which had been limed would revert back to oak rather than pine when abandoned. Further studies by Ebermayer (1876) added principles concerning the role of leaf litter and organic detritus as a vital link in the mineral cycling between vegetation and soil. He also found that the mineral content of plants of a given species would become less with increasing precipitation over its climatic range.

The specific effects of fire on mineral cycling and subsequent fertility of soil were dealt with by Sir Humphrey Davy (1815). He found the effect of periodic burning of vegetation on shallow sandy soils brought about a loss in fertility of the site due to loss in mineral elements; but that this did not occur on heavier and deeper soils. Considerable insight into the effect of periodic fire on fertility has been derived from the practice of shifting cultivation. Reviews such as by Conklin (1963) indicate that the basis of shifting agriculture is the enrichment of the soil by the ash content of mineral elements. This increase in mineral elements in the soil brings about the temporary luxuriant growth typical of the crop phase of the shifting cultivation cycle. The enrichment of nutrients found by Greenland & Nye (1959), and Nye (1958) is temporary. Elements such as phosphorus, potassium, and nitrogen were found to be especially accumulated by ashing the forest. The balance in the cycle is achieved by the regrowth of the vegetation fallow stage which Viro (1969) has found may need from six to thirty years to achieve. The time required for this depends upon many variables among which are the original nutrient content of the soil, the climate and its effect on the rates of the processes, the chemical reactions of the interacting elements, and the chemical reactions themselves, ranging from simple ion exchange, formation of precipitates, chelation and complex ion formation etc., all affecting process magnitudes and rates.

The literature of recent times has tended to substantiate the general principles which had been established in earlier centuries. Thus, most authors find a surface enrichment of mineral elements after fire due to the addition of ash (Grier, 1975; Hanes, 1965; Heyward & Barnette, 1934; Klemmedson _et al_, 1962; Moore, 1961; Neal, 1965; Mc Coll & Grigal, 1975; Sampson, 1944; Smith, 1970; Stark,1973; Vlamis _et al_, 1955; Vlamis & Gowan, 1961). The relative enrichment depends upon the species of plants making up the burned vegetation and their contents of each element as Sampson, 1944 indicates. Viro (1969) mentions that whether the elements are retained in the soil, or lost by leaching depends upon their solubilities

under the prevailing chemical conditions of the soil, and the ion exchange capacity of the soil. Thus, potassium is readily leached and possibly lost, while calcium and phosphorus are retained (Mc Coll & Grigal, 1975) (Rowe & Hagel, 1974; Viro, 1967). Almost all investigators have found an increase in soil pH as a result of this increase in mineral matter. The change in physical characteristics of the soil due to fire may affect its retention of mineral elements (Tarrant, 1956).

The effects on the vegetation of these additions of mineral elements to the soil by fire has usually been to bring about a luxuriant growth of herbaceous species and increased growth of surviving woody plants (Christensen,1973; Sampson, 1944; Sweeney, 1956). This regrowth vegetation has higher mineral content in these initial years following the fire (Sampson, 1944), and a tie-in to the faunal uptake of mineral elements is the greater desirability of this growth for forage and browse by deer and other animals (Bissell, 1951; Dietz et al,1958, Sampson, 1944; Wilson, 1969).

The fire type ecosystem is most vulnerable to losses of mineral elements at the time that it is burned, and the ash and soil are relatively unprotected by vegetation. Volatilization during burning, wind erosion losses of ash (Sampson, 1944), and erosion by surface runoff (De Bano & Conrad, 1976; Sampson, 1944), leaching of ash mineral constituents, and soluble mineral forms are all relevant processes described in the literature. Whether these are good or bad depends partly upon value judgements based upon objectives of management, or the balance of damages and benefits in the areas receiving these mineral elements.

Studies I am currently involved in with regard to mineral cycling in fire type ecosystems are concerned with the effects of periodic burning in shifting cultivation on the mineral element balance between soil and vegetation in a tropical forest area in Thailand; and the elemental balance in lysimeter tanks growing California chaparral species. These will be briefly described below.

LUA SHIFTING CULTIVATION EXAMPLE

The various systems of shifting cultivation give examples of the effects of fire on mineral cycling. An example is the Lua forest fallow system which I studied in Thailand (Zinke et al, 1970). The Lua people of northwest Thailand operate a system of shifting cultivation which consists of burning the forest after it has been cut and dried out while lieing on the ground, growing a crop of upland rice in the ash fertilized soil, and then allowing a fallow period of nine years during which the forest regrows. The cycle is then repeated. The effect of this practice on the mineral element cycling of the site is shown in the data presented in table 1. As has already been established in the past literature, the effect is to increase the content of the surface soils in Calcium, Magnesium, and Potassium immediately after the fire and ash deposition with the effect gradually diminishing with regrowth of the forest vegetation. Indicative of this was a pH of 6.7 immediately after the fire, declining to 6.6 1 year later, and reducing to 6.2 by seven years. A near by old forest control soil had a pH of 6.0.

As the vegetation regrows after fire, there is a redistribution of the accumulation of elements deposited in the soil back to the regrowing vegetation. This is shown in table 1.

These results from a shifting cultivation study involving periodic fire indicate that under the conditions of the climate, vegetation, and the soil there is a period recharge of the cation exchange capacity of the soil with basic cations from the ash immediately after burning, this is then gradually depleted by the uptake to storage in the regrowing woody biomass of the forest.

These effects of periodic recharge of the soil by mineral elements returned in the ash resulting from fire probably occur in the case of macchia and chaparral.

MINERAL CYCLING IN LYSIMETERS CONTAINING CHAPARRAL

Since 1936, an installation of lysimeter tanks has been in operation at the San Dimas Experimental forest. During most of this time, the tanks have been occupied by stands of vegetation of each of the major chaparral species of California. Nearly mature stands of the vegetation occupying some of the lysimeter tanks were burned in a fire in August of 1960. The chamise vegetation occupying the tank was then 15 years old. I

Table 1. Distribution of mineral elements in vegetation, leaf litter, ash and soil through various phases of the Lua Shifting Cultivation Cycle compared with a nearby old growth tropical forest. Units-Gram Equivalent Weights per square meter (soil to 20cm depth)

ELEMENT & COMPARTMENT	CYCLE PHASE				
	CURRENT BURN	1-year	4-year	7-year	OLD FOREST
CALCIUM					
Vegetation	0	.04	.67	.71	14.08
Leaf litter	0	.09	.43	.39	0.74
Ash	.28	0	0	0	0
Soil	7.57	9.08	6.29	4.45	1.44
MAGNESIUM					
Vegetation	0	.07	.28	.29	6.52
Leaf litter	0	.05	.22	.27	.33
Ash	.06	0	0	0	0
Soil	3.90	3.59	2.26	2.05	1.74
POTASSIUM					
Vegetation	0	.06	.46	.46	6.27
Leaf litter	0	.05	.08	.09	.16
Ash	.06	0	0	0	0
Soil	.38	1.49	.61	.51	.84
TOTAL					
Vegetation	0	.17	1.41	1.46	26.87
Leaf litter	0	.19	.73	.75	1.23
Ash	0.40	0	0	0	0
Soil	11.85	14.16	9.16	7.01	4.02

have analysed the original soils with which the tanks were filled in 1936 and 1940, and soil samples taken immediately before the fire in 1959, immediately after in 1960, 1961, 1969, and 1975.

An example of the shifts in mineral element balance that take place during the growth of a shrub stand typical of chaparral, the effect of fire on this, and the subsequent shifts in mineral balance as the stand regrows is seen in table 2.

The data shown are for the soils and vegetation of an open pit lysimeter at Tanbark Flat on the San Dimas Experimental Forest of the Pacific Southwest Forest and Range Experiment Station, U.S.F.S. . This lysimeter (lysimeter B) was first filled with uniformly mixed soil in 1940, and following a brief period of annual grass cover was planted to chamise (Adenostoma fasiculatum) in 1946, and sampled for soil and vegetation

Table 2. A Mineral Element balance history of thirty five years of growth of a chamise stand in Lysimeter B, Tanbark Flat, San Dimas Experimental Forest.
(Gram Equivalent Weights per square meter)

			COMPARTMENTS					
			VEGETATION			ASH	SOIL	
Year	Element	Foliage	Stems	Litter	Total		0-7.5cm	0-1m
1940	Ca	0	0	0	0	0	8.58	109.4
	Mg	0	0	0	0	0	6.93	87.8
	K	0	0	0	0	0	0.16	1.8
	Total	0	0	0	0	0	15.17	199.9
1959	Ca	.23	.33	.40	.96	0	8.83	116.9
	Mg	.05	.04	.08	.17	0	6.35	88.7
	K	.01	.03	.01	.05	0	0.12	1.4
	Total	.29	.40	.49	1.18	0	15.30	206.9
1960 FIRE	Ca	0	0	0	0	.50	9.6	
	Mg	0	0	0	0	.15	5.8	-
	K	0	0	0	0	.05	0.3	
	Total	0	0	0	0	.70	15.7	
1961	Ca					.39		
	Mg					.23		
	K					.01		
	Total					.63		
1969	Ca	.17	.38	2.90	3.45	0	9.44	
	Mg	.05	.09	1.36	1.50	0	-	
	K	.05	.18	.28	0.51	0	0.24	
	Total	.27	.65	4.54	5.46	0	-	
1975	Ca	.14	.41	1.76	2.31	0	10.23	135.3
	Mg	.04	.09	0.71	0.84	0	7.31	98.2
	K	.03	.11	0.18	0.32	0	0.18	2.1
	Total	.21	0.61	2.65	3.47	0	17.72	235.6

Note: minus sign (-) denotes missing data.

content of mineral elements in 1959. In July of 1960, it was completely burned over by fire, and sampling of the ash was made a week later, and also a year later in 1961. The regrowing chamise vegetation from sprouts and the soil were sampled in 1969, and finally in 1975. Analyses were run on all of these samples for mineral elements as well as carbon,

nitrogen, and mass of vegetation and leaf litter. Five replicates were taken of the surface soil, the leaf litter, and the ash samples, and a soil profile in the center of the lysimeter was sampled to 122cm depth (48"). Total analyses were run on the foliage, stems, leaf litter and ash by perchloric digestion and atomic absorption spectrophotometry for the mineral elements, and exchangeable cation and cation exchange capacity determinations were made on the soil samples by 1N ammonium acetate leachate. The runoff water from the lysimeter was also analysed for a single winter after the fire occured. This was also done for comparison under the other chaparral species which were burned by fire, but these data are too extensive to be reported here.

The uptake of these cations represents a decrease in soil storage of those ions which are limited in amount, or have limited recharge from soil minerals in the particular soil. In the case of this soil, apparently it is potassium which is not replenished, and for which the uptake of potassium by vegetation up to 1959 is directly accounted for by a loss of potassium in soil storage. As reported in the literature review, there are different amounts of storage between various vegetation parts, stems and foliage. Most of the storage of calcium and potassium was in the chamise stems before the fire, with magnesium storage being greater in amount in the foliage at that time. However, in the sprout regrowth following the fire, most of the storage of these elements was in the stems, but as reported in the literature review both the stems and the foliage had higher mineral element contents. Leaf litter, the organic detritus on the soil surface, had nearly as much or more calcium and magnesium in storage as the vegetation both before and after the fire. There was much more total storage of mineral elements in both the vegetation and leaf litter in the post fire stand. Thus, the effect of fire in this example was to increase the proportion of ecosystem mineral element storage in the vegetation up to the 15 year interval of sampling after fire.

The ash sampled one week after the fire contained nearly all of the potassium in the previous litter and vegetation storage, most of the magnesium, but only half the calcium. The immediate surface soil sampled at the same time showed an increase in calcium equivalent to the remainder. The ash one year later in 1961 had lost about one third of the mineral elements, except for a slight increase in magnesium.

Runoff water was sampled from the lysimeter for the first three storms after the fire. The storms were on November 5, 12, and 26. Potassium contents were 0.68, 0.48, and 0.31 milliequivalents per liter, and Calcium contents were 1.74, 1.40, and 1.24 m.e. /liter. These quantities represented a return to amounts normal for nearby unburned lysimeters with the same vegetation by the fourth storm. Thus, losses of the mineral elements will probably be sizeable only in the first few storms after the fire. The magnitude of this loss would of course depend upon the intensities of the first few storms following the fire.

Soil storage amounts of the mineral elements in terms of exchangeable cations changed consistent with the effects of vegetation uptake, litter decomposition, ash input, and probable slow release mineral weathering during the thirty five years of this study. As can be seen in table 3, Calcium increased consistently through this time in both the surface soil storage (to 7.5cm), and in storage to one meter depth; Magnesium showed a similar trend in total one meter depth storage, but fluctuations in surface soil storage that probably correspond to plant uptake, or to displacement by the larger quantities of recycling calcium. Potassium showed a decrease in both the storage in surface soil horizons as well as in total 1 meter depth storage indicating less recharge from mineral sources to balance plant uptake, and probable losses from occasional subsoil seepage. However there is a striking increase in surface soil potassium storage which is highest immediately after the fire, declining gradually but still apparent 15 years later.

The change in soil pH throughout the 35 year history of this stand is of interest in that it shows a range from 5.8 to 7.4; the high pH being that in the ash sampled immediately following the fire, and the lowest pH's being those of the 14 year old prefire period, and in the soil 15 years after fire.

The history of the mineral balance of this single stand of chamise under relatively controlled conditions of lysimeter growth thus illustrates the major principles already established in the earlier literature on this subject. It is apparent that there is a soil enrichment of mineral elements due to ashing by fire, that this effect gradually decreases with time after the fire. There is increased mineral element storage in the sprouting regrowth vegetation after the fire, and an

increased amount in the organic detritus returned to the soil surface as leaf litter. Presumably as the literature indicates the intensity and relative effects with regard to the various elements will vary depending upon the species, the soil and geologic conditions, and the interaction with climate.

CONCLUSIONS

Mineral cycling in fire type ecosystems is dominated by the periodic ashing of the mineral element storage in the vegetation and organic detritus on the soil surface. The effects of these large additions of mineral elements at once may last through the period between this burning process. Provided the soil has the storage capacity to receive these elements, and there is no undue loss due to leaching or erosion at the time of maximum vulnerability immediately following the fire, this flush of mineral elements to the soil will be followed by a corresponding increase in vegetation storage, and leaf litter storage of these same elements. The effect of fire in the case of examples presented in this paper was to increase the mineral element in the biologically active portion of the ecosystem. However there are probably climatic, soil, or vegetation variations in Mediterranean areas that would give many different results, and it data specific for all these conditions do not yet exist.

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WATER BALANCE IN MEDITERRANEAN SCLEROPHYLL ECOSYSTEMS[1]

Philip W. Rundel[2]

Abstract: Environmentally imposed conditions of summer drought provide severe physiological stresses on plants in Mediterranean ecosystems. Distinctive patterns of hydrology and growth-form rhythms are produced in these regions by the prevailing climatic conditions, and as a result water relations plays an extremely important role in determining community structure. To successfully survive Mediterranean conditions, plants have evolved a complex of morphological and physiological adaptations enabling efficient use of water in maximizing photosynthetic production. The characteristic role of fire in Mediterranean ecosystems provides additional factors affecting water relations.

Key words: Water relations, drought stress, transpiration, hydrology, interception, sclerophyll shrubs, chaparral.

INTRODUCTION

The severity for plant growth of the summer-dry seasonality of Mediterranean climates has been well-known for many years. Plant species growing in any of the Mediterranean climate regions of the world all face the common problem that moisture is typically limiting for growth during the summer months when favorable air temperatures for high rates of photosynthetic production occur. With winter precipitation, soil moisture is recharged but ambient temperatures are too low for efficient growth (Mooney and Dunn 1970a, Miller 1947) (figure 1). Woody evergreen sclerophylls reach a peak of growth activity in the late spring, but commonly are able to maintain at least low levels of net production during every month of the year.

In this paper, I will discuss the broad subject of water balance in Mediterranean climate ecosystems, with special respect to

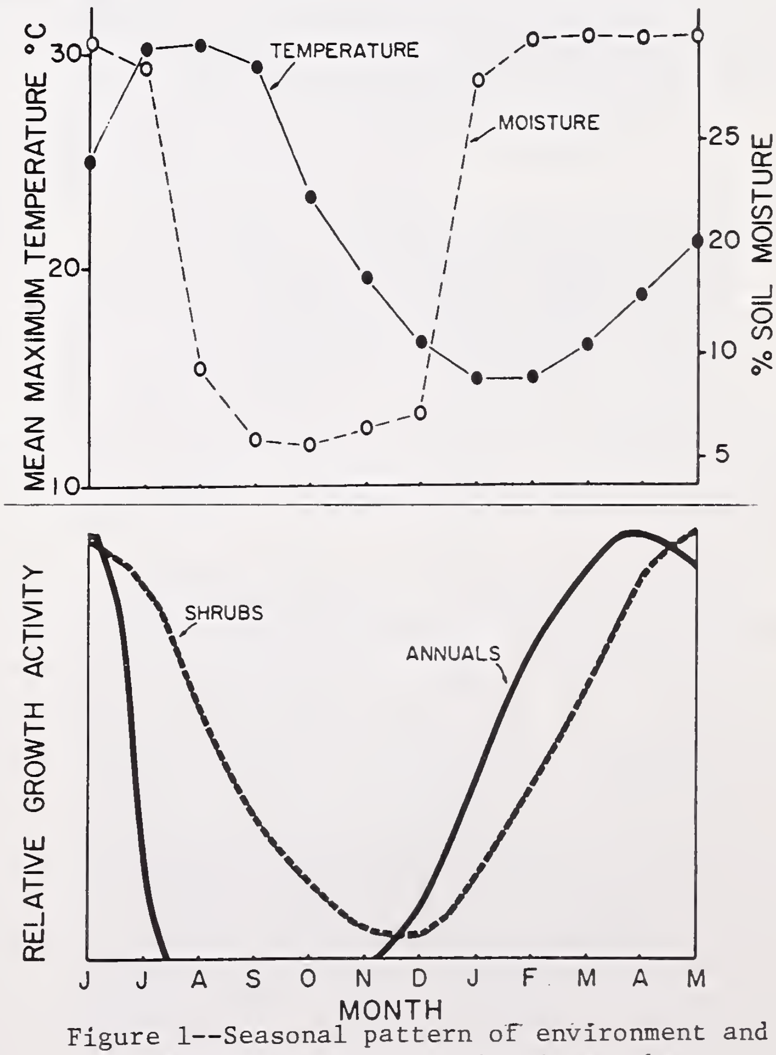

Figure 1--Seasonal pattern of environment and relative growth activity in southern California. From Mooney and Dunn (1970a).

[1]Presented at the Symposium on Environmental Consequences of Fire and Fuel Management in Mediterranean Ecosystems, Palo Alto, Calif. Aug. 1-5, 1977.

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the evolutionary strategies utilized by evergreen sclerophylls in adapting to the water stresses of these environments. Hydrologic cycles, community changes along aridity gradients, and growth rhythms of sclerophyll communities will all be considered in addition to morphological and physiological adaptations to improve plant water relations.

HYDROLOGIC CYCLES

Complete data on hydrologic cycles in Mediterranean-scrub communities have not been made, but scattered data exist on many pathways of water movement in these ecosystems. Major studies of moisture cycling in chaparral watersheds were carried out at the San Dimas Experimental Forest of the U.S. Forest Service from 1937 to 1959. Input, disposition and storage of precipitation was investigated using both natural stands of chaparral and large lysimeters (Rowe and Colman 1951, Colman and Hamilton 1947, Sinclair and Patric 1959, Zinke 1959, Patric 1961, 1974, Sinclair 1960, Rowe and Reimann 1961, Hill 1963). A rough water budget for Monroe Canyon at San Dimas is shown in table 1, with data for a range of annual precipitation extremes. Deep drainage through extensively faulted bedrock was commonly the major pathway of water loss, although this loss could only be determined indirectly.

Table 1--Water budget for Monroe Canyon, San Dimas Experimental Forest, California. Data for 1940-41 and 1950-51 represent extreme years from Hill (1963). Data for 1943-44 from Rowe and Coleman (1951). Adapted from Mooney and Parsons (1973).

Water Budget	1940-41	1943-44	1950-51
Precipitation (mm)	1321	798	305
Interception Loss	9.6%	8.7%	16.8%
Evapotranspiration	26.9%	35.4%	83.2%
Streamflow	21.1%	14.6%	T
Deep Drainage	42.2%	41.4%	T

In a dry year, however, only trace amounts of either deep drainage or steamflow occurred, and most water was lost through evapotranspiration. Interception loss (direct evaporation from leaf and stem surfaces) was almost two times as high in a dry year as in a normal or wet year. In 1943-44, with only slightly more than mean precipitation, soil profiles reached field capacity in mid-December. By mid-March, transpirational water loss was drawing on stored soil moisture and the -15 bar level of soil moisture stress was reached over a broad period varying from 20 June to 18 October, depending on local microhabitat conditions (Rowe and Colman 1951). Residual soil moisture may be present below the root zone, however (Pillsbury et al, 1963).

Studies in other areas indicate that runoff and deep drainage may often be minor pathways of water loss. Specht and Jones (1971) found no runoff and little drainage in heath vegetation in Australia. Miller et al. (unpublished data) found similar results for chaparral communities on polar facing slopes in San Diego County, California, but major water loss through drainage on equator-facing slopes. Simulation studies indicate that virtually all of the incoming precipitation on polar-facing slopes is lost through transpiration, due largely to the high leaf area indices (LAI) on these slopes. On equator-facing slopes with lower leaf area indices, transpiration and soil evaporation are significant pathways of water loss but much less important than drainage.

GROWTH RHYTHMS

Growth rhythms of Mediterranean-scrub vegetation are clearly related to soil moisture availability. The majority of annual growth occurs in spring. Corresponding to periods of precipitation and favorable ambient temperatures, and productivity in evergreen communities gradually decreases as summer drought progresses (Mooney and Dunn 1970, Mooney et al. 197 Dunn et al. (1976). The relationship of soil moisture and temperature to relative growth activity in shrubs and annuals at a southern California chaparral site are shown in figure 1. A significant exception to this pattern is present in southern Australia, however, where vegetation phenology is conspicuously out of phase with the Mediterranean climate (Specht and Rayson 1957a, Groves 1965, Groves and Specht 1965, Specht 1973). Dominant woody taxa - including Eucalyptus, Banksia, and Casuarina - and perennial grasses typically begin growth in late spring or early summer and continue to grow actively well into summer. Only a few native taxa such as Leptospermum and many geophytes show a characteristic spring growth pattern (Jones 1968a, 1968b). Introduced Mediterranean annuals also show a spring pattern (Specht and Rayson 1957a). For the majority of the species, however, growth begins late and continues sporadically throughout the summer utilizing stored soil moisture or irregular summer rains (Holmes

1960, Martin and Specht 1962, Specht and Jones 1971). This unusual growth rhythm, hypothetically related to the tropical origin of the flora (Specht and Rayson 1957a, Specht 1973) indicates that phenological adjustment is a slow process and maybe interrelated with other adaptive responses.

Comparative studies of growth rhythms and soil moisture patterns in relatively mesic and relatively xeric community-types in Mediterranean regions indicate that more mesic communities may exhaust soil moisture earlier than more xeric communities and consequently face longer periods of summer drought. Martin and Specht (1962), studying Eucalyptus associations in South Australia, found more mesic communities had high indices of evapotranspiration and regularly endured a soil moisture drought of more than one month. More xeric communities with lower rates of evapotranspiration did not deplete soil moisture reserves and no drought period occurred in an average year. In California chaparral, similar patterns are present. Open stands of vegetation on relatively xeric equator-facing slopes maintain available soil moisture much longer into the summer than more mesic communities with greater cover on pole-facing slopes (Ng and Miller 1977).

COMMUNITY CHANGES ALONG ARIDITY GRADIENTS

Distinctive changes in dominant plant life-forms and morphological structures of plants within individual life-forms occur along aridity gradients in Mediterranean ecosystems. In both southern California and central Chile a latitudinal aridity gradient extends from evergreen sclerophyll forest at the moist end through evergreen shrub communities to coastal malacophyll scrub to finally coastal scrub with succulents at the dry extreme. (Mooney et al 1970, Rundel, 1978, Weber et al. 1977). Similar patterns of change between evergreen and deciduous communities are present along elevational gradients (Mooney and Harrison 1972, Weber et al. 1977). An example of this can be seen in the foothill communities of Sequoia National Park (figure 2). Deciduous oak woodlands (Quercus douglasii) dominate all aspects below 400 m, but evergreen chamise stands (Adenostoma fasciculatum) and mountain misery (Chamaebatia foliolosa) communities dominate higher foothill slopes on south-facing slopes. On upper north-facing slopes, mixed evergreen and deciduous buckeye woodlands (Aesculus californica) are characteristic, while pure deciduous black oak (Quercus kelloggii) woodlands dominate the highest foothill zone. In addition to these structural changes in community dominance, morphological changes in characteristics of single life-form types occur (Mooney et al. 1974, Parsons and Moldenke 1975, Parsons 1976). All of these community structural and morphological changes along aridity gradients have been related to physiological and morphological strategies of water use efficiency in maximizing photosynthetic production (Mooney and Dunn 1970b, Harrison et al. 1971, Miller 1976).

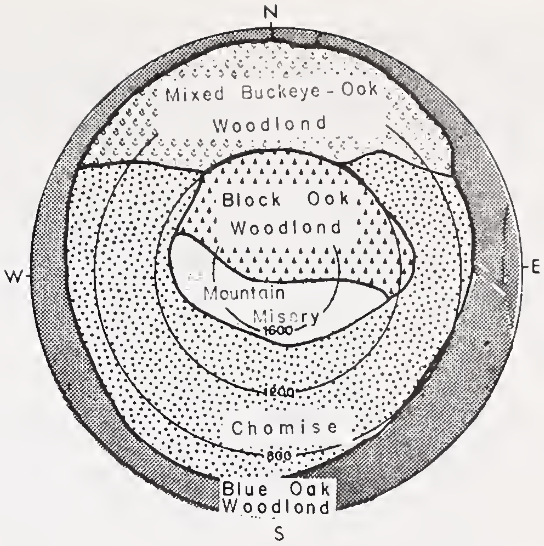

Figure 2--Dominant plant community distribution along elevational and aspect gradients in the foothill zone of Sequoia National Park, California.

Many local environmental factors may change soil moisture balance abruptly over short distances, producing structural changes in communities. Important factors of this type include slope aspect, slope runoff, drainage patterns, soil texture, soil organic matter, and soil wettability.

ADAPTATIONS TO IMPROVE PLANT WATER RELATIONS

Morphological and physiological adaptations to improve water relations of Mediterranean-climate sclerophylls may take a variety of forms (Oppenheimer 1960). Two groups of adaptations may be considered. The first of these are biological means of increasing the rate and amount of water absorbed by the root system. Since water uptake is a function of the water potential gradient between the soil and root tissue divided by the combined soil and root resistances, biological means of increasing uptake would include adaptations to increase gradient of water potential between root and soil and adaptations to reduce the soil and root resistances to water flow. Related to these mechanisms, plants

may also influence the amount of soil moisture available for uptake by concentrating precipitation through stem flow. Although some data exist relating to the significance of stem flow and to the adaptive significance of patterns of rooting behavior, as described below, these mechanisms are still poorly investigated. Almost nothing is known concerning the importance of root resistances in regulating water uptake rates in sclerophyll shrubs.

Considerably more data are available on morphological and physiological strategies to reduce transpirational water loss in evergreen sclerophylls (Mooney and Kummerow 1971). Transpirational water loss may be expressed as a function of the vapor pressure gradient between air in the intercellular spaces of the leaves and outside air divided by the sum of boundary layer resistances of the air and leaf resistances. A schematic representation of the controlling factors of transpiration is shown in figure 3, where leaf resistance (r_1) is subdivided into a variety of component parts. Since the thick cuticle of most sclerophylls prevents any significant cuticular water loss, the majority of adaptational strategies to minimize transpirational water loss while maintaining high water use efficiency for production all relate to efficient stomatal control mechanisms. These control mechanisms are affected by both morphological and physiological strategies regulating the relative magnitude of components of leaf resistance.

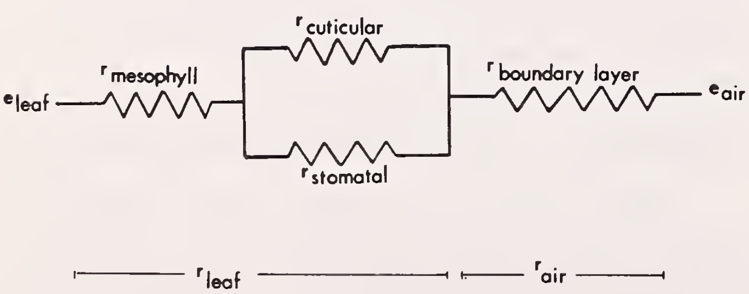

Figure 3--Schematic diagram of resistances to transpirational water loss from a leaf. Transpiration is proportional to the relative gradient of water vapor pressure from leaf to air (^{e}leaf, ^{e}air) divided by the sum of leaf and air resistances. Leaf resistances include mesophyll resistance, cuticular resistance, and stomatal resistance.

Morphological Adaptations

Foliage Area and Morphology

Efficient interception of precipitation by foliage of Mediterranean-climate shrubs and the associated concentration of this moisture by stem flow may be an important adaptation to improve plant water relations. This pattern of interception has been the subject of many studies in California (Bauer 1936, Rowe 1948, Hamilton and Rowe 1949, Corbett and Crouse 1968), Israel (Shachori and Michaeli 1965, Shachori et al, 1967) Australia (Slatyer 1965, Specht 1957), and France (Rapp 1969, Rapp and Romane 1968). Mixed canopies of California chaparral, commonly intercept 25-35% of the incident precipitation (Hamilton and Rowe 1949, Miller et al, unpublished data) Specht (1957) calculated 35% leaf interception for a single heath shrub in South Australia. Between individual species, however, this rate of interception varies considerably. Species with high leaf area indices, stiff upright branches and smooth bark generally produce the highest rates of interception.

The significance of concentration of precipitation by stem flow on soil moisture patterns has been shown by Specht (1957a) for heath vegetation in South Australia. Two relatively broad-leaved species, *Xanthorrhoea australis* (Liliaceae) and *Banksia ornata* (Proteaceae) intercept a large percentage of incident precipitation, and their orientation of leaves allows most of this intercepted moisture to flow down their stems to enter the soil near their root stocks. This pattern of interception produced sharp gardients of soil moisture with precipitation following periods of drought (figure 4). Soil beneath the shrubs was near field capacity, while soil beneath small leaved low shrubs a few feet away was still below -15 bar wilting point. Although both *Xanthorrhoea* and *Banksia* intercept large amounts of incident precipitation, the lower concentrations of soil moisture under the former results from a large evaporative loss of intercepted water on the leaf surfaces and from trapped water among fragments of resin between leaf-bases. The formation of centers of concentration of precipitation under large shrubs and zone of rain-shadow around their peripheries gives these individual, considerable competitive advantage over low small-leaved species associated in the same communities.

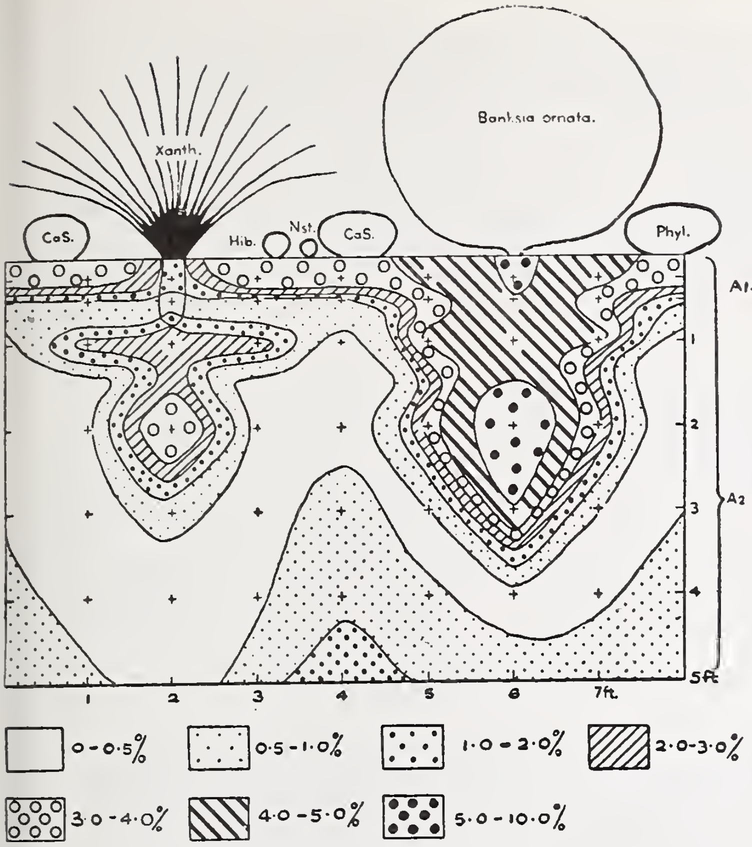

Figure 4--Patterns of soil moisture under Xanthorrhoea australis and Banksia ornata with first precipitation following summer drought. From Specht (1957a).

Root Systems

The development of extensive root systems in Mediterranean scrub vegetation is an important adaptation to minimize periods of drought stress by increasing moisture uptake and storage. These root systems may be extensive vertically, horizontally, or both. In all cases, however, a capacity to absorb water from a large volume of soil or tap ground water supplies provides an important competitive advantage during summer periods of drought. Hellmers et al. (1955) studied the rooting characteristics of California chaparral plants, identifying three distinct categories of root structure. Woody evergreen shrubs such as Adenostoma, Quercus, Heteromeles, and resprouting species of Arctostaphylos and Ceanothus have deeply penetrating root systems reaching to 8 m or more below the surface. These taxa are also characterized by a swollen lignotuber just under the ground surface. Tree-form oaks in California oak woodlands have been found to extend as deep as 27 meters (Lewis and Burgy, 1964) and Mediterranean maqui vegetation taps water from depths of over 8 m (Shachori et al. 1967). Woody evergreen shrubs characterized as reseeders following fire form a second category of rooting behavior with coarse later root growth for exceeding the depth of root penetration. In the final group, comprising malacophyll subshrubs and succulents, a shallow fibrous root system is present. These roots do not penetrate beyond 1.5 m in depth. Root systems of Australian heath plants have been described by Specht and Rayson (1957b).

The change from deeply penetrating roots in evergreen shrub communities to shallow fibrous roots in coastal deciduous communities is correlated with a gradient of increasing aridity, with a lack of available ground water supplies in the coastal communities. Desert shrub communities, even more arid, are also dominated by fibrous-rooted taxa except locally where deep-rooted phreatophytes dominate habitats with available ground water.

Where soils are very shallow and fissures are lacking in the parent material Mediterranean sclerophyll shrubs are restricted to shallow root systems. In these situations, many species have evolved succulent root tissues associated with large fibrous root masses to provide water storage for the summer drought period. Hanes (1965) found that succulent root tissues in Adenostoma sparsifolium provided limited moisture reserves to enable this species to maintain physiological activity well into the summer drought period (figure 5). Fuchsia lycioides in the coastal matorral of central Chile shows a similar adaptation (Rundel, unpublished data).

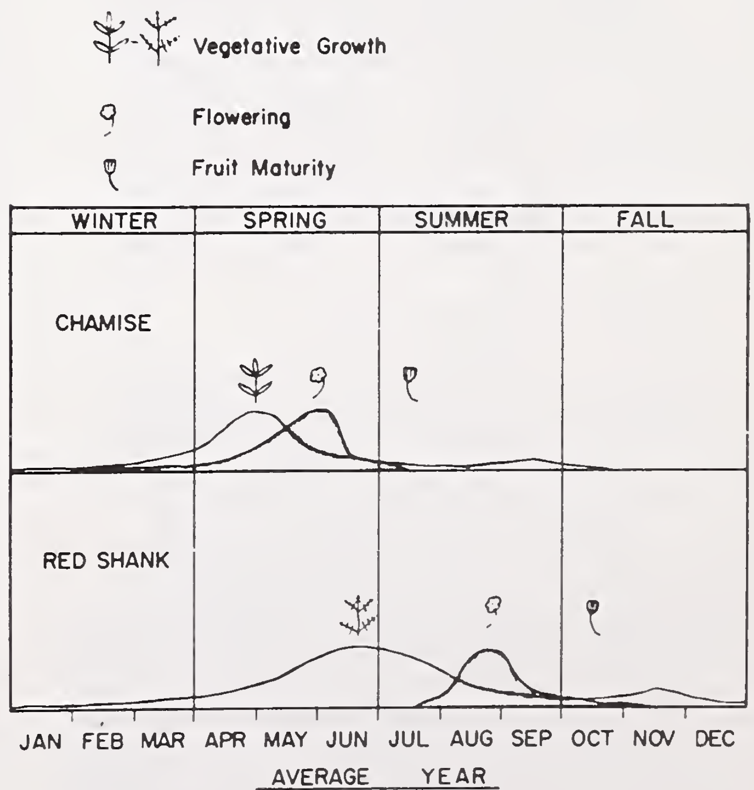

Figure 5--Seasonal phenological activity in Adenostoma fasciculatum and A. sparsifolium. From Hanes (1965).

Fahn (1964) has described an adaptive mechanism in desert root systems where anatomical structure of major horizontal and vertical roots differ. He suggests that wider and longer vessel elements in horizontal roots (increasingly so with distance from the stem) compensate for moisture stress by decrease root resistances to water flow. Detailed anatomical studies of root systems of Mediterranean scrub vegetation have not been carried, but similar mechanisms may be present.

Detailed comparative studies of root systems of California chaparral and Chilean matorral shrubs are currently being carried out (Kummerow and Krause, unpublished data; Ng and Miller 1977) and should provide a better understanding to the adaptive characteristics of root structures for plant water relations. Preliminary data for California has found root-shoot ratios of 0.4 to 0.8, but root-shoot surface area ratios vary from 6 (evergreen shrubs) to 40 (malacophyll subshrub) (Kummerow et al., unpublished data). Fine root density is 64 g dry weight per m^2 under a shrub canopy and 45 g m^{-2} between canopies. Experimental greenhouse studies by Kummerow have also indicated a linear relationship between root volume and leaf area in *Adenostoma fasciculatum*.

Water storage in woody lignotubers of shrubs adapted to resprouting after fire may be an important means of reducing drought stress. Following late summer or fall fires where soil moisure is unavailable for plant growth, 50 cm or more of resprouting height growth may occur rapidly. Fahn and Leshem (1963) described living libriform fibers and fiber tracheids in the xylem of many malacophyll shrubs which hypothetically may increase the water storage capacity of woody tissues.

Leaf Morphology and Orientation

A variety of characteristic features of leaf morphology and orientation in evergreen Mediterranean-climate shrubs are adapted to minimize transpirational water loss. Smaller leaf sizes allow efficient convective heat exchange and minimize dependence or transpiration cooling of leaves during periods of high temperature associated with summer drought. Additionally, smaller leaf sizes have a low ratio of blade tissue to water conduction tissue and are thus are less subject to injury from desiccation, other factors being equal (Eckardt 1952). A pattern of decreasing sizes of evergreen leaves along gradients of increasing aridity is evident in the Mediterranean zones of both California and Chile.

Relative vertical orientation of leaves provides means of regulate leaf uptake of solar radiation and thus control leaf energy balance. In more xeric sites, therefore, vertical orientation of leaves is an important adaptation to reduce leaf heat load and thereby water loss. Good examples of this can be seen in *Arctostaphylos* and *Garrya* in California and *Colliguaya* in Chile.

The necessity to reduce cuticular water loss in Mediterranean-climate evergreens has led to the evolution of relatively thick cuticles in these species. Examples of mean cuticle thickness for dominant California chaparral and Chilean matorral species are shown in table 2. With each area, however, cuticle thickness is not related to relative drought tolerance.

Seasonal Leaf Variability

Seasonal leaf variability provides an important mode of drought adaptation in many Mediterranean- climate shrubs. This type of seasonal change, occurring primarily in malacophylls, but in a few sclerophylls as well, is achieved in a variety of ways (Orshan 1964). In general, however, the pattern is reduction of the transpirating surface area. On a dry weight basis Mediterranean chamaephytes in Israel lose 45-75% of their transpiring body in summer from maximal levels in spring (Orshan and Zand 1962, Orshan 1964). The absolute level of spring leaf biomass is a function of seasonal precipitation and microhabitat conditions, but the relative reduction of leaf biomass is relatively constant for good and bad years for water availability. Many malacophyll scrubs, of course use a extreme form of leaf biomass reduction and become totally leafless with the onset of drought.

The reduction of leaf biomass can be simply accomplished by leaf abscission with the onset of summer drought. Commonly, however, a gradual morphological shift in leaf morphology occurs as water stress increases. In *Coridothymus capitatus* (= *Thymus capitatus*) and *Sarcopoterium spinosum* (= *Poterium spinosum*) in Israel, small rosette-like summer leaves develop (Orshan 1964) as spring leaves are shed. Under very favorable conditions these may grow longer. In *Teucrium polium*, these small leaves elongate slowly over the summer, with the initial size increasing in late summer and fall. *Arbutus menziesii*, a Pacific Coast sclerophyll woodland species, branch buds produce a determinate number of leaves regardless of moisture conditions during development (Morrow 1971, Morrow and Mooney 1974). As a result, leaves produced

in wet spring are large with relatively low leaf resistances to water loss while dry spring result in smaller, more sclerophyllous leaves with higher resistances.

Table 2--Comparative leaf characteristic of California chaparral and Chilean matorral sclerophylls. Data from Fischbeck and Kummerow (1977).

Species	Leaf size (Cm^2)	Leaf density (g/cm^2)	Stomata frequency ($no./mm^2$)		Cuticle thickness (µm)	
			upper	lower	upper	lower
California						
Rhus ovata	13.0	.021	-	167	13.0	12.1
Heteromeles arbutifolia	7.0	.020	-	251	7.5	5.0
Arctostaphylos glauca	5.2	.027	66	65	9.9	10.1
Quercus agrifolia	4.4	.013	-	336	5.5	2.5
Quercus dumosa	2.1	.014	-	495	5.2	3.8
Ceanothus leucodermis	1.4	.012	-	197	4.1	3.1
Ceanothus greggii	1.1	.037	-	crypts	12.8	
Adenostoma fasciculatum	0.06	.15	-	105	- 11.1 -	
Chile						
Kageneckia oblonga	7.1	.021	1	225	13.0	8.0
Cryptocarya alba	5.9	.020	-	386	7.9	4.2
Lithraea caustica	5.8	.026	-	174	15.3	9.8
Quillaja saponaria	3.9	.021	79	276	10.8	9.6
Colliquaya odorifera	1.9	.027	86	115	7.3	5.9
* *Trevoa trinervis*	1.1	.008	-	157	4.2	3.5
* *Satureja gilliesii*	0.1	.008	-	126	6.7	4.4

* deciduous

variability is reduction of absolute plant transpiration rates during summer drought. Orshan (1964) found late summer rates of whole plant transpiration were only 11-18% of maximal spring values for four shrubs in Israel. Desert shrubs in the northern Negev reduced their loss to 1-10% of spring levels.

In *Heteromeles arbutifolia*, a sympatric evergreen sclerophyll shrub in central and northern California variable numbers of leaves of approximately the same size are produced over a range of water stresses (Morrow and Mooney 1974). Seasonal leaf changes in other evergreen sclerophylls is poorly investigated.

The physiological significance for water relations of all forms of seasonal leaf

Under severe drought conditions, physiological separation of root and corresponding branch sectors of shrubs may allow differential survival of neighboring radial sectors of individual shrubs, hypothetically reducing water stress for surviving sectors. The presence of such physiologically semi-independent branch segments has been established in desert plants (Ginzburg 1963 Evenari *et al*. 1971; Orshan 1972), but have not been investigated in Mediterranean-climate shrubs.

Stomatal Frequency and Position

Although some authors have suggested that increased stomatal frequency is related to increasing drought adaptation (Salisbury 1927; Walter 1949) data for Mediterranean-climate sclerophyll vegetation does not support this hypothesis. Wood (1934) found that generic and family affinities of Australian sclerophylls were more important than environmental in determining stomatal frequency. Comparative stomatal frequencies of important California chaparral and Chilean matorral shrubs, show considerable variability in each area (table 2). Mean values for sclerophyll shrubs and trees in the Mt. Lofty are of South Australia are 145 (± 19) for the Proteaceae, 302 (± 5) for the Epacridaceae, 301 (± 22) for the myrtaceae, and 277 (± 21) for the Leguminosae (Wood 1934). These values are similar to stomatal frequencies of sclerophylls on sandstone ridges around Sydney - Proteaceae 162, Epacridaceae 296, and Leguminosae 185 (Carey 1938). Variability within families is great, however.

Position of stomata is not strongly correlated with xeromorphic adaptation in sclerophylls. In Mediterranean-climate areas of Australia, stomata commonly occur on both upper and lower leaf surfaces (Grieve 1954). In the Epacridaceae, however, they are confined to the lower surface. Sclerophyll shrubs in California and Chile only rarely have stomata on the upper surface, and then in relatively low frequencies (table 2). Desert plants commonly have stomata on both surfaces, both more abundantly on the upper surface (Evenari and Richter 1937).

Physiological Adaptations

Root-Soil Resistances

Little data exist to suggest if individual Mediterranean-scrub species regulate their water relations through differential root and soil resistances to water flow. In both California and Chile, plant water potential recover from drought within a few days of the onset of precipitation in the fall, indicating that new root growth is not required for water uptake. The significance of biological factors of root biomass and anatomical structure in influencing interspecific variation in root resistance has not been investigated, but the work of Fiscus and Kramer (1975) suggests that significant differences may exist between species.

Plant Water Potential

As soil water potential decreases the physiological ability of competing plant species to absorb water from the soil varies considerably. This variation can be seen in seasonal patterns of dawn and midday water potentials for a number of evergreen California chaparral shrubs (Poole 1974, Poole and Miller 1975). Three distinct types of patterns are evident in these species (figure 6).

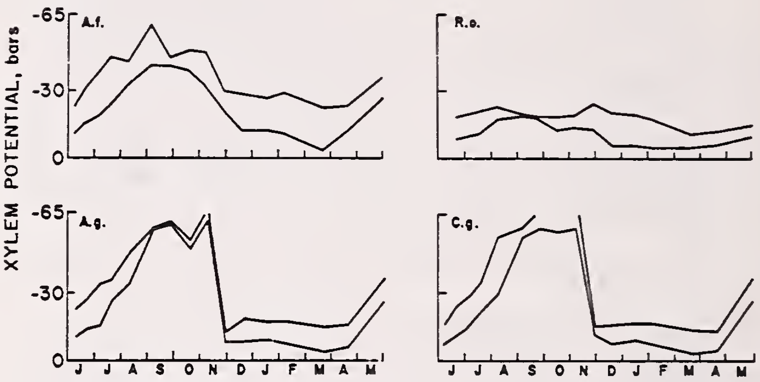

Figure 6--Seasonal patterns of xylem pressure potential for four California chaparral shrubs. Af = *Adenostoma fasciculatum*, R.o. = *Rhus ovata*, A.g. = *Arctostaphylos glauca*, C.g. = *Ceanothus greggii*. From Miller *et al*. (unpublished data).

Shallow-rooted species such as *Arctostaphylos glauca* and *Ceanothus greggii* increase stress steadily from late spring to mid-November when the onset of fall precipitation causes water stress to drop precipitously. In the deeper-rooted *Adenostoma fasciculatum* lower xylem pressure potentials are reached earlier in the summer but midsummer stress is lower than in *Arctostaphylos* or *Ceanothus*. In late summer and early fall, maximum stress begins to decrease well before the onset of fall precipitation, apparently reflecting a decrease in ambient temperature. A similar pattern exists in *Heteromeles arbutifolia* (Poole and Miller 1975). The third pattern, characteristic of *Rhus ovata* and other *Rhus* species, shows a very flat season pattern of water potential with no sharp peak of summer stress. Maximum midday xylem pressure potential never falls below -20 bars (table 3).

Table 3--Plant water relations characteristics of California chaparral and coastal sage scrub species. N and S are north and south slopes at inland site (1000 m), while I and C refer to inland and coastal sites. Data from Poole and Miller (1975) and Morrow and Mooney (1974).

Species		Water Potential at Stomatal closure (bars)	Minimum leaf resistance (sec cm^{-1})	Max RSD (%)	Min RSD (%)
Ceanothus greggii	N	-55	6.0	25.4	5.2
	S			21.8	6.2
Arctostaphylos glauca	N	-55	2.0	26.2	3.5
	S			17.8	3.8
Adenostoma fasciculatum		-50	4.0		
Heteromeles arbutifolia	I	-35	2.5	16.0	5.8
	C			14.2	2.4
Rhus ovata		-20	4.5	13.8	4.5
Rhus laurina	N	-20	5.0	8.2	0.5
	S			10.4	0.4
Rhus integrifolia	N	-20	5.0	12.4	2.4
	S			15.5	2.4
*Salvia apiana				35.4	5.0
Arbutus menziesii		-35	2.0		

* deciduous

Deciduous shrubs typically show seasonal patterns of the first type, with high maximum stresses. Artemisia californica has xylem pressure potentials below -65 bars for more than four months during the summer and early fall on equator-facing slopes in coastal sites.

Similar patterns are present in Chilean matorral shrubs. Colliguaya odorifera follows the first pattern, with a gradual decrease in xylem pressure potential to -45 bars with the onset of drought, and a rapid reduction of stress with the onset of precipitation in the fall (Montenegro and Riveros 1977). Kageneckia oblonga has the same pattern with maximum stress of -60 bars (Riveros and Montenegro 1977). Lithraea caustica, like Rhus in the Anacardiaceae, shares the pattern of relatively flat seasonal progression with no sharp peaks of summer stress and no values below -20 bars (Riveros and Montenegro 1977).

Salvia apiana, however, has considerably higher minimal potentials in summer of -35 bars (Poole and Miller 1975) (table 3). Minimum seasonal potentials of Satureja gillesii and Trevoa trinervis in Chile are -60 bars (Riveros and Montenegro 1977).

The magnitude of diurnal variations in water potential under summer stress conditions are also variable. The majority of California species show sharp diurnal patterns with gradients of -10 to -20 bars from dawn to midday (Poole and Miller 1975). Under the same summer conditions, Rhus has a flat diurnal curve with a maximum gradient of -5 to -10 bars. These same two patterns are repeated

in Chile with high diurnal variations in most species but a flat curve in Lithraea (Riveros and Montenegro 1977).

Although not considered in detail here, the seasonal patterns of water potentials in oak woodland communities have been investigated (Griffin 1973, Syvertsen 1974). Habitat selection by individual species is strongly correlated with these seasonal patterns.

Leaf Conductance

Leaf conductances decrease as expected with decreasing water potential in mediterranean evergreen shrubs. This response can be seen in data for six chaparral shrubs in figure 7. At high water potentials, Arctostaphylos glauca has the highest conductance. This is consistant with the high growth rates of this species.

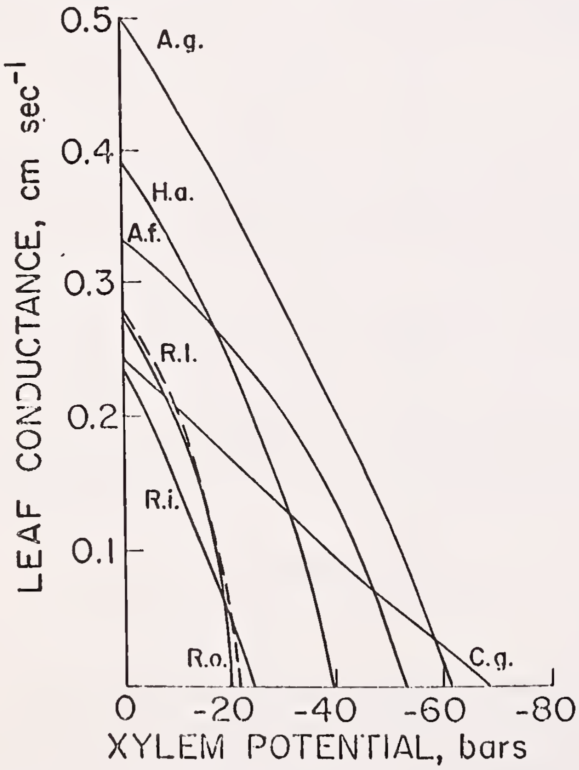

Figure 7--Relationship of leaf conductance to xylem potential in California chaparral shrubs. Abbreviations as in Figure 6 with H.a. = Heteromeles arbutifolia, R.i. = Rhus integrifolia, R.l. = Rhus laurina. From Miller et al. (unpublished data).

Although the conductance of Ceanothus greggii is relatively low at high water potentials, it has the highest conductance of any of the species studied at low water potentials. Heteromeles and Adenostoma have intermediate responses, demonstrating moderate water use strategies. The response of three species of Rhus is puzzling, however, with conductance reaching zero at only -20 bars. These data, consistant with the observed patterns of water potential in the field, indicate that Rhus should be disadvantaged in its rate of production relative to other species since conductance is directly related to CO_2 uptake.

Transpiration Rates

Numerous studies of transpiration rates in Mediterranean-climate sclerophylls have been made (table 4), but many of these are old and need verification. A clear pattern is present, however.

Table 4--Transpiration rates in Mediterranean-climate sclerophylls.

Species	Rate of Transpiration mg dm^{-2} min^{-1} moist Conditions	dry Conditions
Yugoslavia (maquis) - Guttenberg in Grieve (1954)		
Laurus nobilis	2.66	1.66
Arbutus unedo	8.50	2.91
Olea europaea	3.06	3.75
Ceratonia siliqua	3.00	
Pistacia lentiscus	2.50	2.16
Italy (maquis) - Rouschal in Grieve (1954)		
Ruscus aculifolius	1.22	1.01
Viburnum tinus	5.53	1.1
Laurus nobilis	4.26	0.72
Arbutus unedo	6.20	2.22
Olea europaea	12.80	3.39
France (garrigue) - Eckardt (1952)		
Teucrium flaum	12.0	1.1
Coronilla glauca	20.4	2.0
Bupleurum fruticosum	9.0	1.0
South Australia - Wood (1923, 1924)		
Acacia aneura		1.38
Acacia victoriae		4.75
Eremophila scoparia		1.15
Eremophila glabra		0.85
Casuarina lepidophloia		2.25

Species	Rate of Transpiration mg dm^{-2} min^{-1} moist Conditions	dry Conditions
Western Australia - Grieve (1954)		
Eucalyptus calophylla		7.8
Hardenbergia comptoniana		1.2
Stirlingia latifolia		5.8
Banksia attenuata		8.3
Victoria, Australia (sand heath) - Grieve (1954)		
Banksia collina		4.0
Leptospermum laevigatum		1.1
Hibbertia sericea		3.5
Platylobium obtusangulum		2.2
California (chaparral) - Cooper (1922)		
Adenostoma fasciculatum		1.0-1.8
Arctostaphylos		0.66-1.1
Arbutus menziesii		0.5
Chile (matorral) - Riveros and Montenegro (1977)		
Kageneckia oblonga		1.2
Lithraea caustica		1.9
* Satureja gilliesii		2.2
* Trevoa trinervis		2.9

* deciduous malacophyll

Under relatively dry conditions, efficient stomatal closure and thick leaf cuticles reduces transpiration rates in most sclerophylls to less than 4.0 mg cm^{-2} min^{-1}. Malacophyll species in the same enviroment commonly have transpiration rates 4-5 times higher. The observed low rate of transpiration in sclerophylls, a function of both physiological centrol of stomatal response and morphological leaf characteristics, is clearly of adaptational value in control water loss during summer drought. Midday stomatal closure during these drought periods minimizes transpirational water loss, while at the same time allowing low levels of positive net CO_2 assimilation to continue through the summer.

Photosynthesis and Respiration Response to Drought

With increasing drought stress, evergreen sclerophylls commonly show a pattern of midday stomatal closure, with peaks of positive net photosynthesis in the morning and mid-afternoon (figure 8).

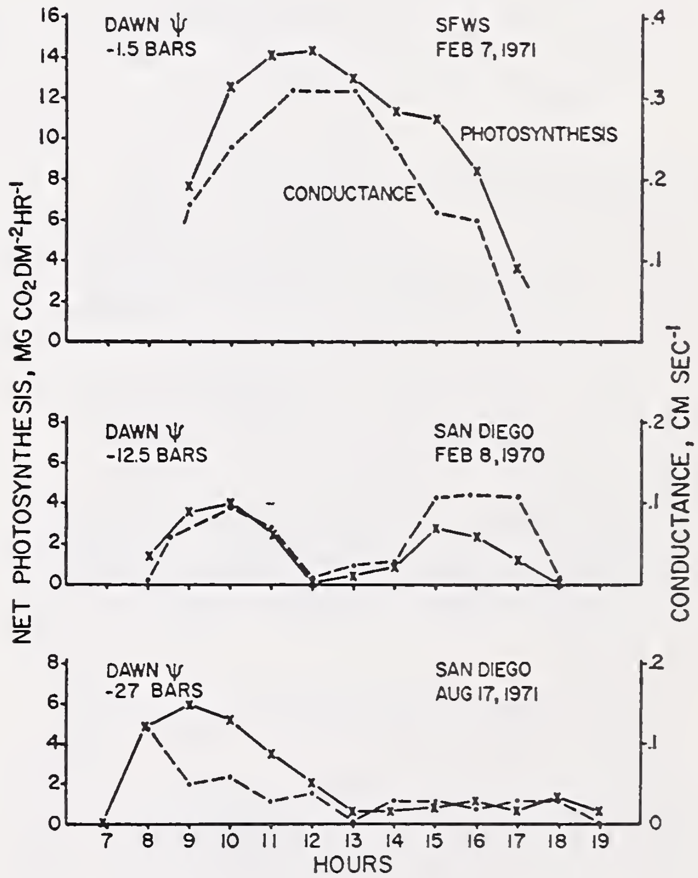

Figure 8--Diurnal cycle of photosynthesis and leaf conductance in Heteromeles arbutifolia. From Mooney et al. (1975).

With low water potentials in late summer, a morning peak of photosynthesis remains, but the afternoon level of photosynthesis is only slightly above the compensation point, (Mooney et al. 1975). Under extreme drought, dormancy may occur (Harvey and Mooney 1964, Morrow and Mooney 1974). Similar patterns of summer

drought response have been found in sclerophyll shrubs of the Mediterranean region (Guttenberg 1927, Guttenberg and Buhr 1935, Larcher 1960, 1961a, 1961b), but Australian shrubs appear better adapted for summer growth (Hellmuth 1971).

An important mechanism allowing these shrubs to maintain growth under conditions of relatively low water potentials is the sclerophyllous structure of the leaves (Dunn et al. 1976). Low tissue water potentials are maintained in sclerophyll leaves with relatively small changes in cell volume (relative water content), as shown in figure 9 for Californian and Chilean sclerophylls. These values are similar to those of other xerophytic species (Slatyer 1960).

Respiration rates also show drought adaptations to maintain high water use efficiency and allow net positive CO_2 assimilation to occur at low levels of tissue water potential. In Adenostoma, respiration rates lower with increasing drought stress, thereby increasing levels of net photosynthesis (Hanes 1965). Sharp rises in respiration in sclerophylls following precipitation have been reported for the Mediterranean region (Harder et al. 1931). Reduction of respiration with drought is much more pronounced in evergreen sclerophylls than related winter deciduous species, and this mechanism results in clear adaptive value for such sclerophylls in Mediterranean climates (Mooney 1969, Larcher 1960).

IMPACT OF FIRE ON WATER RELATIONS

Water relations of Mediterranean-scrub communities may undergo significant changes following fire. These changes may result from any combination of direct effects of the combustion and heat of the fire: 1) organic matter combustion and associated changes in soil physical properties; 2) alteration of soil wettability; 3) increase in surface runoff; and 4) reduction of allelopathic chemicals. The relative magnitude of these effects, however, is highly dependant on the structure of the original vegetation, the heat of the fire, and the time since the last fire.

Organic matter plays several important roles in water relations and its loss during fires is important (Agee 1973). Aggregation of soil particles is improved by organic matter, resulting in larger non-capillary pore volumes and thus higher rates of water infiltration secondly, surface litter and organic matter acts to reduce surface evaporation from soils.

Infiltration of water into chaparral soils may be significantly decreased by the formation of water repellent layers after fires (DeBano et al. 1967, Savage 1974, Scholl 1975, Cory and Morris 1969). Factors relating to the formation of these water repellent layers have recently been reviewed by DeBano et al. (1977). Hydropholic compounds from decomposing plant litter and from microorganisms accumulate in soil litter between fires. When a fire occurs, high temperatures decompose organic matter and coat soil particles with these compounds. With increased heat intensity the water repellent zone becomes deeper and broader. Very high temperatures destroy hydropholic compounds at the soil surface but sharp temperature gradients move the zone of water repellency to greater depths. The effect of water repellent compounds is more pronounced on coarse-textured sand and sand loan soils than on fine-textured clay soils where particle surface area is large (DeBano et al. 1970).

Following fire, the combined effects of loss of vegetation cover, decreased organic matter content of soil, and formation of water repellent soil layers all act to increase runoff and associated erosion. Studies in central California found tremendous increases in surface runoff between burn and control plots. (DeBano and Conrad 1976). For the first rainy season, steep and gentle chaparral slopes in burn plots had runoff of 780,000 and 500,000 l/ha respectively. For control plots, comparable values were 24,000 and 4500 l/ha.

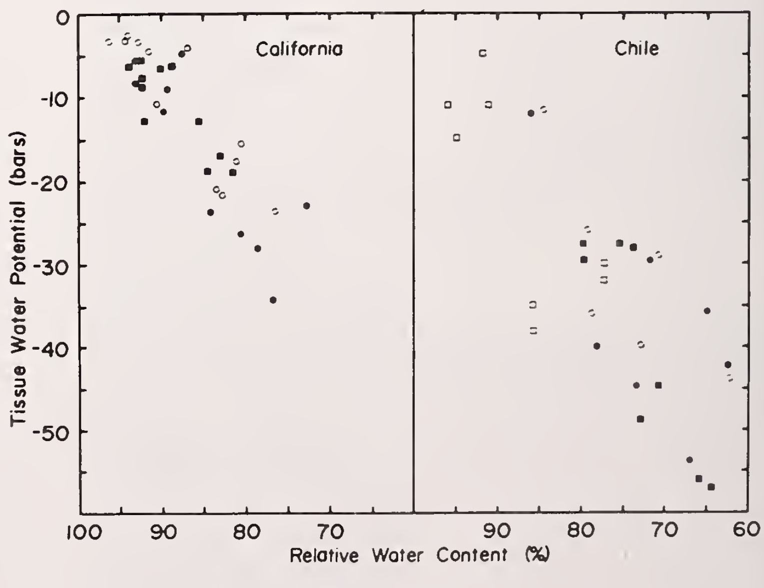

Figure 9--Relationship between tissue water potential and relative leaf water content for California and Chilean sclerophyll shrubs. From Dunn et al. 1976.

THE CARBON CYCLE IN MEDITERRANEAN-CLIMATE EVERGREEN SCRUB COMMUNITIES[1]

Harold A. Mooney[2]

Abstract: Evergreen shrubs of Mediterranean-climate regions have a relatively low above-ground productivity (ca. 400 g $m^{-2}yr^{-1}$). This is due to: 1) the relatively low photosynthetic rates that characterize these plants even under optimum conditions, 2) the photosynthetic rate-limiting summer drought, 3) the large allocation of carbon to roots, and 4) the high construction costs of the shoot tissue. Above-ground standing biomass accumulates at about 150 g $m^{-2}yr^{-1}$. At equilibrium, litter fall and decomposition occur at a rate somewhat above 250 g $m^{-2}yr^{-1}$. A rough estimate indicates that for one Californian chaparral area about 100 g m^{-2} of dry matter is lost through fire per year.

Key words: Photosynthesis, allocation, biomass, litter fall, production.

INTRODUCTION

Plants gain carbon through the photosynthetic process, in which carbon dioxide is reduced to sugar compounds with light energy. These compounds in turn are utilized as energy sources and building blocks for the plant structures, leaves, stems, and roots, which in turn harvest the environmental resources: light, nutrients, and water. The form and arrangement of plant structures depend largely on the spatial and temporal distribution of the environmental resources. Since there is a distinctive resource pattern common to Mediterranean-climate regions, it is not surprising that plants growing in these regions are similar in growth form and metabolism.

The rates of carbon fixation by plants are also governed both directly and indirectly by the environment; directly through the effects of nutrient and water level on the photosynthetic process and indirectly through apparent limitations imposed on the type of photosynthetic apparatus in order to achieve optimal water-use efficiency under the environmental constraints of a summer-drought climate.

The rate of photosynthesis and the subsequent pattern of carbon apportionment determine the rate of biomass accumulation. It appears that these processes are comparable in Mediterranean regions since, as will be shown, biomass accumulation rates are similar in all of them.

Finally, the kinds and amounts of litter produced by plants are strongly determined by the kind of photosynthetic apparatus constructed which, as stated above, is climate dependent. Thus similarities between rates of litter production should be expected in various Mediterranean-climate regions.

These various relationships are examined here as well as the rates of carbon loss to the atmosphere through decomposition and fire (fig. 1).

PHOTOSYNTHETIC CAPACITY

The inherent carbon-gaining capacity of Mediterranean evergreen sclerophylls is generally low when compared to plants of other climatic regions (ca. 5 to 15 mg $dm^{2}hr^{-1}$)

[1]Presented at the Symposium on Environmental Consequences of Fire and Fuel Management in Mediterranean Ecosystems, Palo Alto, Calif. Aug. 1-5, 1977.

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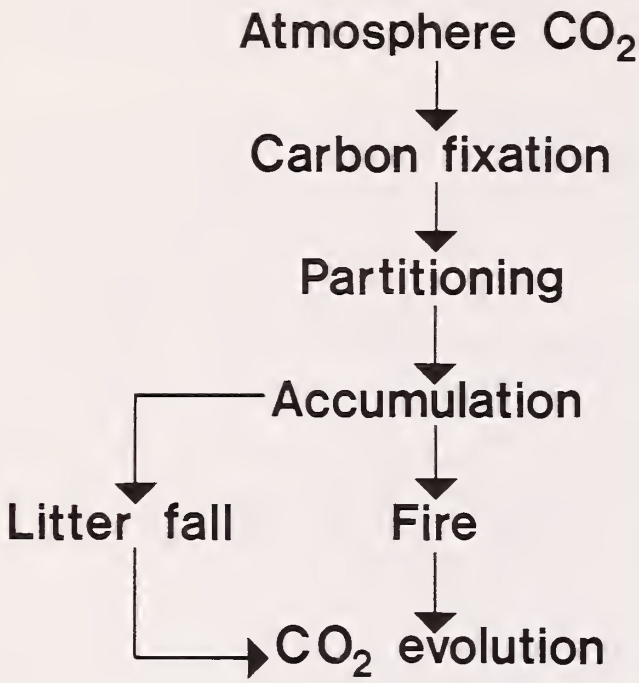

Figure 1--The flow of carbon.

(fig. 2). This is probably an evolutionary result of adaptation to this low-nutrient, water-limited environment (Mooney and Gulmon 1978). Since photosynthesis is often diffusion-limited for long periods during the drought, maintenance of high protein levels necessary for high photosynthetic rates would be nonadaptive. Low nitrogen levels in the environment compound this effect.

The evergreens photosynthesize year-round, but at a reduced rate during the summer drought (fig. 3). The principal seasonal environmental limitation on photosynthesis is soil moisture (Mooney, Harrison, and Morrow 1975). Dunn (1970) found that on a yearly basis Californian chaparral shrubs fixed between 4000 and 7000 g CO_2 $m^{-2}yr^{-1}$. These figures include losses due to dark respiration of the leafy twigs. What follows is a consideration of the fate of this carbon.

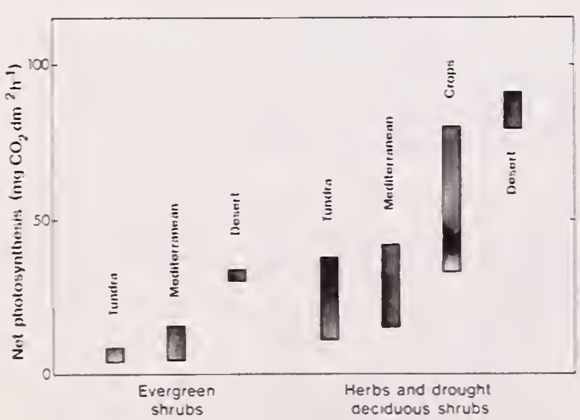

Figure 2--Photosynthetic rates of plants from various community types (from Mooney and Gulmon 1978).

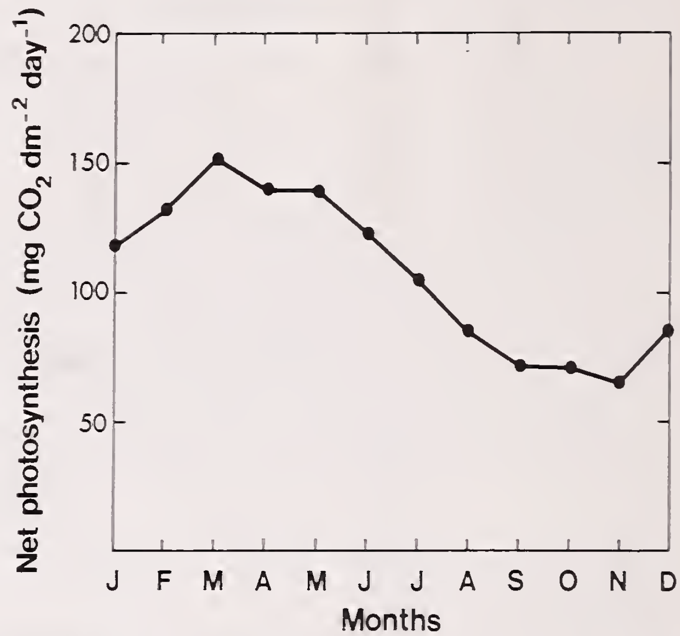

Figure 3--The seasonal change in photosynthetic carbon gain of the Californian evergreen shrub *Heteromeles arbutifolia* (from Mooney, Harrison, and Morrow 1975).

ALLOCATION OF CARBON

The allocation of carbon to various structural parts in Mediterranean-climate evergreen shrubs differs substantially from that found in woody plants of other climate regions. This is seen clearly in figure 4. First, there is a considerable allocation of carbon to root systems in evergreen shrubs, about 40% for California chaparral plants (Kummerow *et al*. 1977). An even higher root allocation has been measured on Australian heath sclerophylls (Jones 1968). This is not surprising, since these environments are water-and-nutrient limited and are characterized by frequent fires. All these features select for high root allocation in plants (Mooney 1972).

In mature chaparral shrubs about 30% of the dry weight will be leaves (fig. 4). This value exceeds that of forest community types. The leaves of Mediterranean-climate evergreen shrubs are distinctive in their high specific weight, the basis of the "sclerophyll" designation.

A study of one California chaparral shrub showed that it allocated a substantial fraction of its carbon to high energy compounds

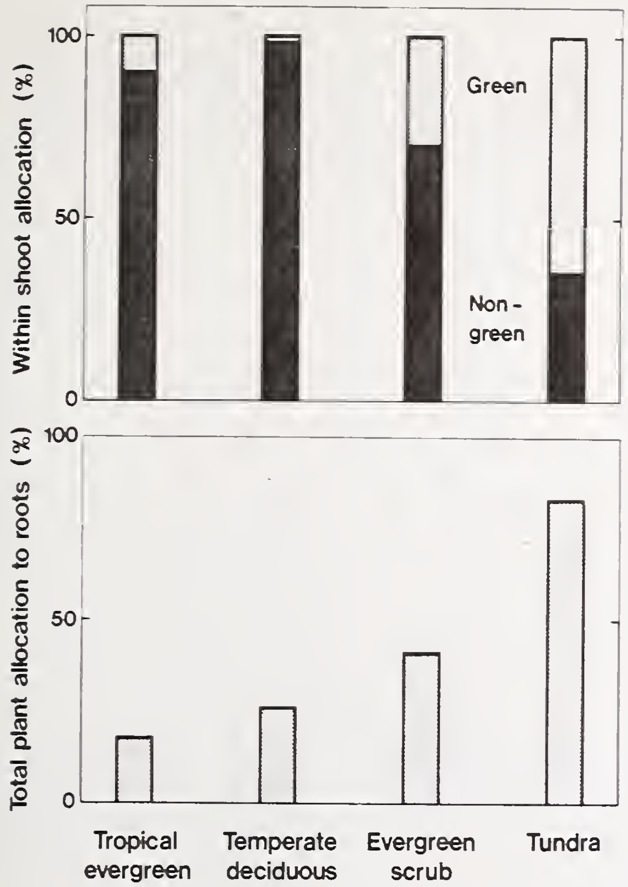

Figure 4--Fractional allocation of carbon to shoot green and nongreen parts in various plant communities (top) and percentage allocation to roots (bottom). Data for tropical evergreen, temperate deciduous and tundra from Rodin and Bazilevich (1967); evergreen scrub shoot allocation from Mooney et al. (1977b); and root allocation from Kummerow et al. (1977).

such as terpenes and phenolics (Mooney and Chu 1974) (fig. 5). This is presumably related to the protection needed from herbivores. Apparently many of the Mediterranean-climate shrubs produce these high-energy compounds, as evidenced in part by their caloric content. Adenostoma fasciculatum, the dominant plant of the California chaparral has a leaf caloric content of over 5200 calories g^{-1} (Mooney et al. 1977a). The compounds that lead to such a high energy content are responsible in part for the high flammability of these plants (Philpot 1969).

Another distinctive feature of Mediterranean-climate sclerophylls is their large surface area to shrub volume (Countryman and Philpot 1970). This feature also leads to high flammability. The significance of the multiple branching system of these evergreen shrubs is not clearly understood, but it may be an adaptation to faster regrowth capacity

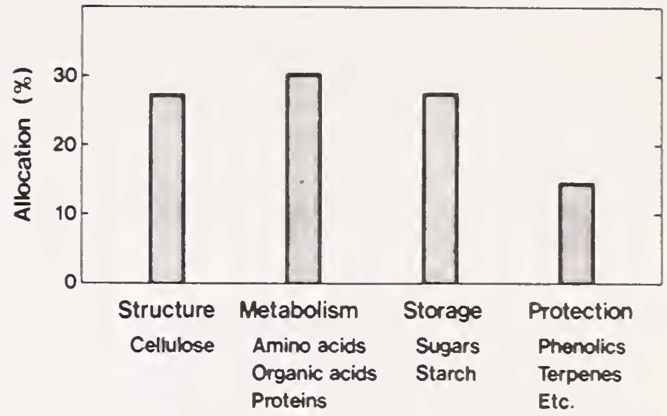

Figure 5--Yearly carbon allocation in the the Californian evergreen shrub, Heteromeles arbutifolia (from Mooney and Chu 1974).

following fire (Miller and Stoner 1978) or to the maintenance of a favorable conductive tissue-to-leaf-area ratio.

BIOMASS ACCUMULATION AND STANDING CROP

The rates of shoot biomass accumulation are quite similar in the evergreen scrub communities of the diverse Mediterranean-climate regions (table 1). Values between 100 and 200 g $m^{-2}yr^{-1}$ have been measured for this community type on four different continents.

These values are derived from aboveground harvests of stands of known age subsequent to a fire. Unfortunately, few time series are available to give an accurate estimate of changes in biomass accumulation with age. There are indications, however, that the rates of biomass accumulation decrease with age. In a study of the heath in southern Australia, Groves and Specht (1965) noted a marked decline in rates of annual biomass accumulation after 15 years. Sampson (1944) noted a similar decline in accumulation rate after only five years of regrowth (fig. 6).

Kruger (1977) notes that between 500 and 1000 g m^{-2} are necessary to maintain a successful burn. Such levels would be attained in 3 to 5 years according to the above accumulation rates.

The amount of dry matter of above-ground plant parts found in mature Mediterranean-climate evergreen scrub plant communities varies roughly between 2500 and 5000 g m^{-2} (table 1), which is considerably less than found in forest types (fig. 7).

Table 1--Shoot biomass accumulation and standing crop for evergreen scrub communities in diverse Mediterranean-climate regions.

Locality	Vegetation type	Annual biomass increment ($g\ m^{-2}$)	Estimate period (yr)	Standing biomass and age of mature stand ($g\ m^{-2}$)	age (yr)
California					
San Dimas[1/]	chamise chaparral	120	0-5	4909	37
		100	0-10		
Boulder Creek[2/]	chamise chaparral	100	0-23	2308	23
No. Calif (Av)[3/]	chamise chaparral	160	0-8	3147	?
France					
Montpellier[4/]	garrigue	150	0-5	2350	17
Le Puech du Juge[5/]	garrigue	138	0-17		
Australia					
Dark Island Soak[1,6/]	heath	64	0-5		
		160	0-5		
		88	0-10		
		--	--	3190	50
South Africa					
Jonkershoek[7/]	fynbos-broad	250	0-6		
	sclerophyll scrub	150	0-10		
		184	0-10		
		150	0-17	2570	17

1/ Specht 1969
2/ Mooney et al. 1977b
3/ Sampson 1944
4/ Specht 1969 (after Long)
5/ Lossaint 1973
6/ Specht, Rayson, and Jackman 1958
7/ Kruger 1977

LITTER FALL

Data on annual litter fall for various community types are readily available and thus comparisons can easily be made. The amount of litter produced in evergreen scrub communities of various geographic regions is rather similar at around 200 $g\ m^{-2}yr^{-1}$ (fig. 8). This is a lesser amount than is produced by Mediterranean-climate or temperate and tropical forests.

The principal period of litter fall in the evergreen scrub of California is in the summer subsequent to spring stem growth (fig. 9); however, in some species litter falls throughout the year (Mooney *et al.* 1975b). In the *Quercus ilex* forests of France litter falls throughout the year but predominantly during the spring growth period (Lossaint 1973).

Litter fall varies from year to year but not to the same degree as twig production. This is shown for the Californian evergreen shrubs in figure 9. In 1972 there was a drought of sufficient magnitude to inhibit virtually all twig growth. Yet litter production during this year was only reduced to two thirds of that in the normal rainfall and growth year that followed. This is because leaves on most evergreen shrubs live for two or more years.

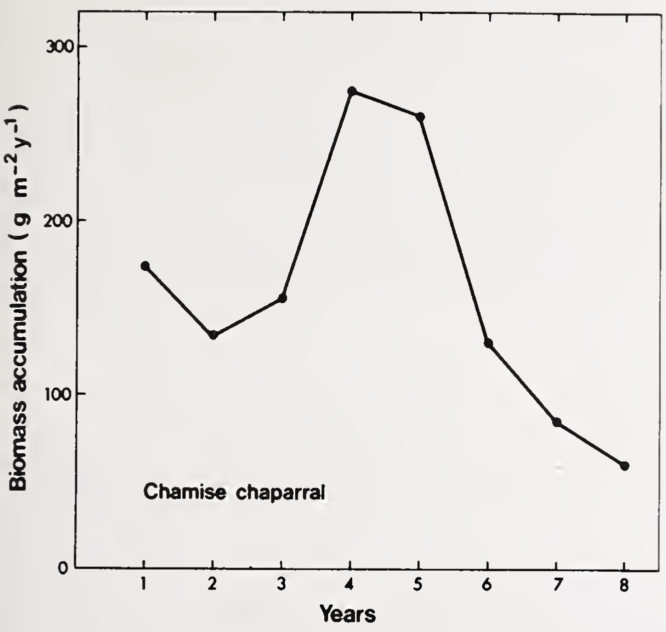

Figure 6--Annual biomass accumulation in chamise chaparral following fire in northern California (from Sampson 1944).

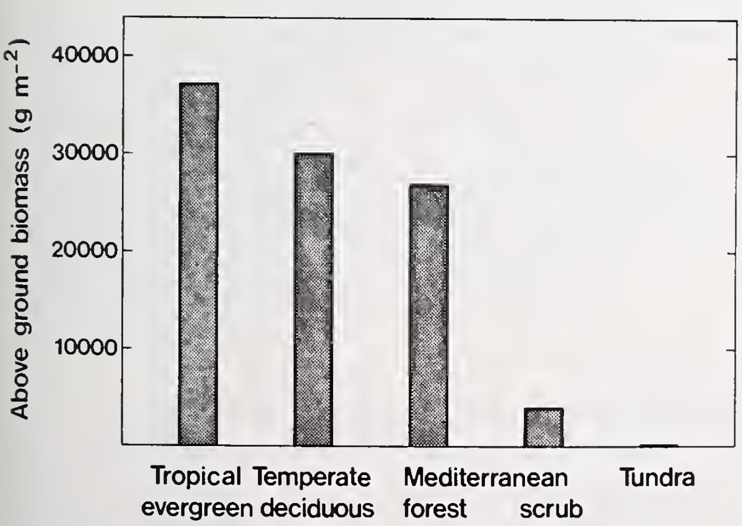

Figure 7--Aboveground standing biomass for various community types. Mediterranean evergreen forest value from Lossaint (1973) for French, Quercus ilex forest; evergreen scrub value an average value from table 1. All other values from Rodin and Basilevic (1968).

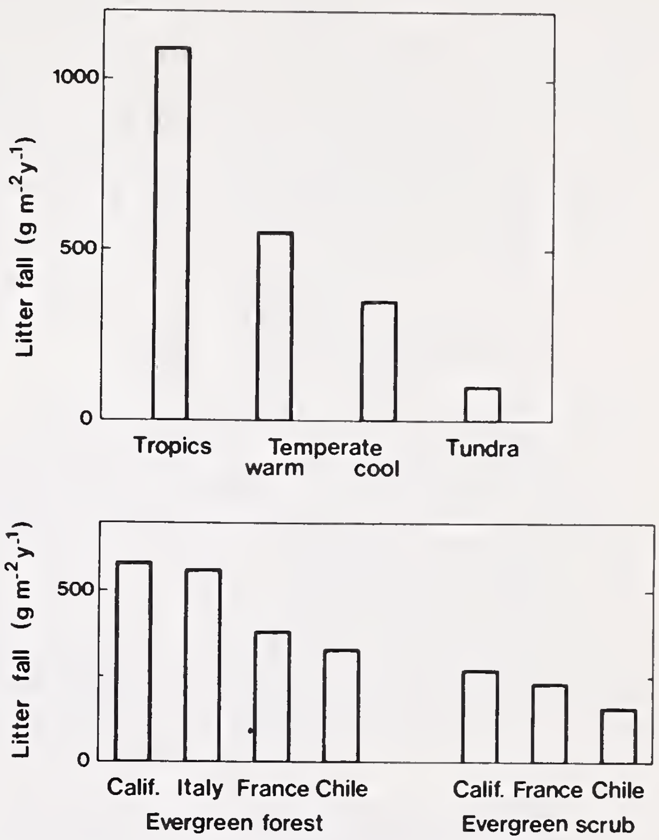

Figure 8--Litter fall in various Mediterranean regions as compared with values for other climatic regions. World values from Bray and Gorham (1964). Evergreen forest values for California, Mooney et al. (1977b); Italy, Susmel et al. (1976); France, Rapp (1971); Chile, Mooney et al. (1977b). Evergreen scrub values for California and Chile, Mooney et al. (1977b); France, Rapp (1971).

In the Californian and Chilean evergreen scrub communities of moderate age, about 80% of the litter fall is leaves (Mooney et al. 1977b).

The time taken to reach equilibrium between litter input and litter decomposition varies greatly between community types and environment. Kittredge (1955) found that in the California chaparral at about 1000 m elevation one of the commonest vegetation types (Adenostoma fasciculatum, Ceanothus crassifolius) reached equilibrium in about 12 years. At the same elevation an oak type took 150 years to equilibrium. Communities found at higher elevations generally had much longer equilibrium times than those at lower elevations.

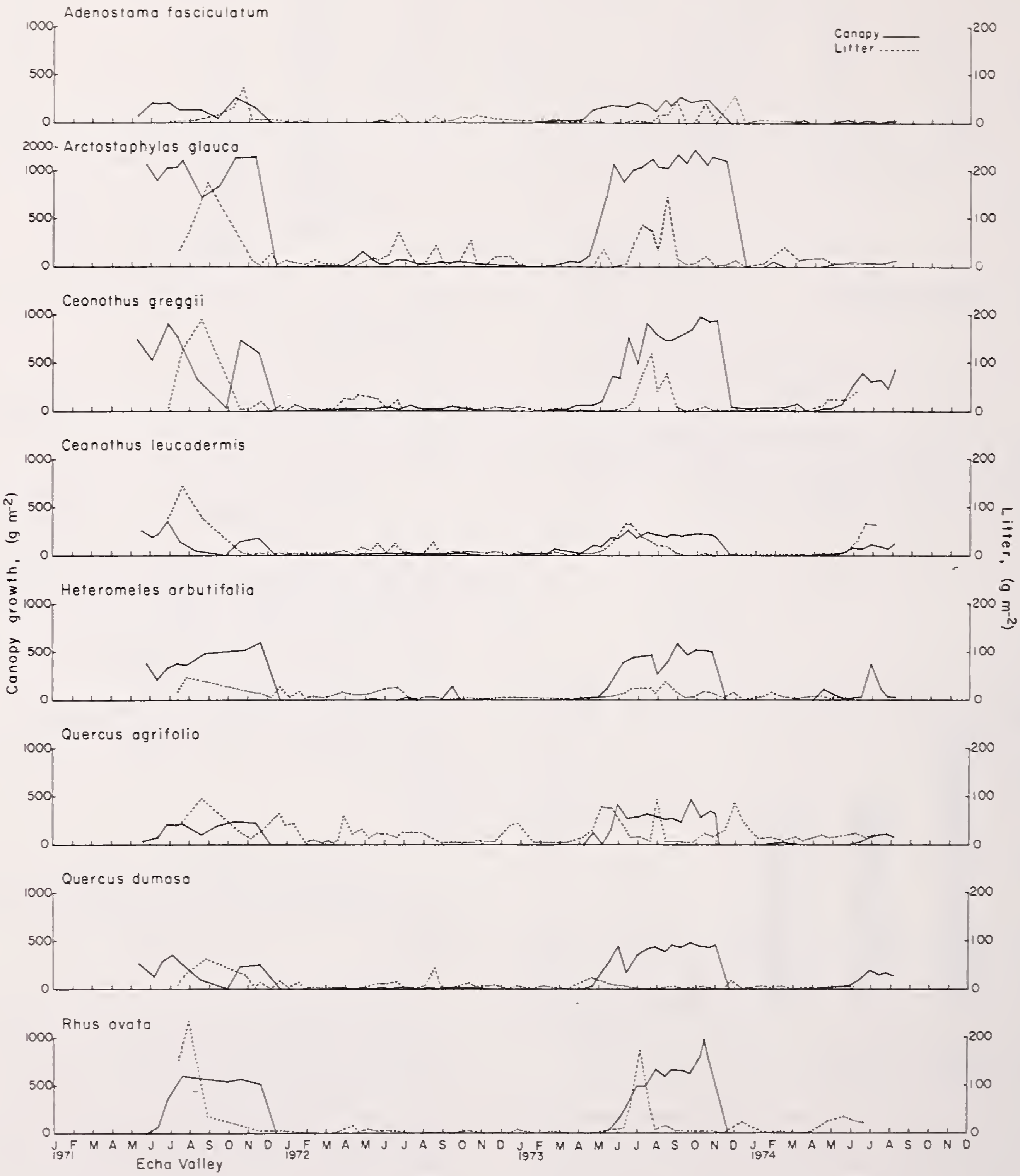

Figure 9--Shoot production and litter fall for a number of evergreen California shrubs and trees (from Mooney <u>et al</u> 1977b).

NET PRIMARY PRODUCTION

An estimate of the annual aboveground production can be derived from the addition of the annual shoot production derived from harvests of known-aged stands and values for annual litter production. Such a procedure gives production estimates for evergreen scrub communities of about 400 g $m^{-2}yr^{-1}$ (fig. 10). This is somewhat below values for an evergreen forest of the Mediterranean region and well below values for temperate and tropical forests.

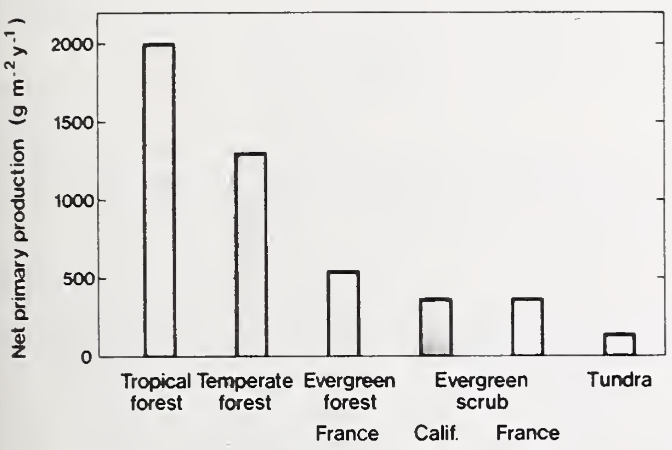

Figure 10--Net aboveground primary production of various vegetation types. Values for tropical and temperate forest and tundra are average values from Whittaker and Woodwell (1971). The remaining values represent average biomass accumulation plus litter fall. Evergreen scrub: California (chaparral) from Mooney et al, (1977b); France (garrigue) from Lossaint (1973), evergreen forest (Quercus ilex) from Lossaint (1973).

How does this production value match the photosynthetic carbon gain given earlier? Chamise chaparral fixes carbon at a rate of 4100 g $m^{-2}yr^{-1}$ (Dunn 1970). As noted previously, as much as 40% of this goes to roots (Kummerow et al. 1977), leaving 2460 g to the shoots. This amount of CO_2 equals about 1500 grams of carbohydrate. To produce one gram of leaf tissue of chamise, 1.7 g of carbohydrate is needed (Miller and Stoner 1978). This high production cost results from the high costs of the production of the numerous secondary compounds present in many of the evergreen sclerophylls. Wood costs for chamise are somewhat less (1.3 g of carbohydrate per gram of tissue). Chamise has a high reproductive output (Mooney et al. 1977b), and such tissue can be costly, although precise values are not known. An overall average cost of 1.6 g of carbohydrate per gram of chamise branch is not an unreasonable estimate. This would then reduce the 1500 grams of shoot carbohydrate to 930 grams of tissue. Loss of CO_2 through maintenance respiration of nonleafy twigs would further converge this value to the 400 g $m^{-2}yr^{-1}$ production value noted above.

COMMUNITY CARBON BALANCE

Data are available that make it possible to compare directly the overall carbon balance for evergreen scrub communities in California and France of comparable ages (table 2). As can be seen, the total amount of biomass present, standing and litter, in the community is the same at about 3500 g m^{-2}. For the chaparral community where the data are available, it is evident that litter production and decomposition are in equilibrium. The amount of accumulated litter is over 1000 grams per square meter.

These values indicate a remarkable comparability in the structure and function of geographically separated plant communities existing under comparable climates.

CARBON LOST THROUGH FIRES

A rough estimate of the carbon lost through fires versus decomposition can be made, using San Diego County, California as a model. Approximately 38% of this county, or 418,400 ha, is evergreen chaparral scrub (Küchler 1977). Marvin Dodge (personal communication) estimates that of this area 4.1% was burned per year during 1941-50, 1.6% per year during 1951-60 and 2.6% per year during 1961-70 for an overall average of 2.8% per year during that 30-year period. However, at the end of this period a single fire (Laguna burn) consumed nearly 18% of the total.

At a biomass level of 500 g m^{-2} (3650 g standing, plus 1350 g litter), a 2.8% loss per year would be 140 g $m^{-2}yr^{-1}$, assuming preferential burning of older stands. In most wildfires the larger-size classes of stems are not consumed, however. Countryman and Philpot (1970) note that in the California chaparral dominant shrub, Adenostoma fasciculatum, only about 60% of the stems will be consumed in most fires. This would reduce our estimate of dry matter loss through fire to about 100 g $m^{-2}yr^{-1}$, or somewhat less than one half the rate of litter decomposition.

Table 2--Comparisons of production characteristics of evergreen scrub communities of California and France of comparable age (17-18 yrs). Values are in g m^{-2}.

	California[1/] Chamise chaparral (Adenostoma fasciculatum Ceanothus crassifolius)	France garrigue (Quercus coccifera)
Standing biomass		
Live	1659	--
Dead	380	--
Total	2039	2350
Annual litter fall	282	230
Annual shoot biomass accumulation	130	110
Annual shoot net production	412	340
Total litter biomass	1359	--
Annual litter decomposition	264	--
Total biomass present (standing plus litter)	3398	--

[1/] Standing biomass and shoot accumulation data for California (San Dimas) from Specht (1969). Shoot accumulation based on closest successive harvests and not for entire growth time period. Litter data for comparable vegetation type and locality from Kittredge (1955). Garrigue data from Lossaint (1973) for Le Puech du Juge.

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FIRE AND FLOOD CYCLES - PAST AND PRESENT[1]

R. G. Vines[2]

Abstract: Regularities in the incidence of disastrous forest-fire seasons in Canada and Southern Australia, and corresponding fluctuations in the yields of non-irrigated crops suggest the existence of quasi-periodic weather variations in both countries. An investigation of rainfall patterns in these two areas has therefore been made; and the annual yields of rainfall-dependent crops, such as wheat and oats, have been used to validate these patterns.

It is proposed that long-term changes in rainfall in the countries mentioned are connected with changes in sunspot activity.

Key words: weather-cycles, forest-fires, sunspots, crop-yields, rainfall, solar activity.

INTRODUCTION

When I first joined the CSIRO Bushfire Section at the end of 1964, I was interested to learn that some Australian foresters believed there was a cyclic pattern in the occurrence of forest fires in South-eastern Australia, and particularly in the State of Victoria. It was well known that, this century, disastrous fires had occurred every 13 years,-in 1913, 1926, 1939, 1952 (and subsequently in 1965). However, it seemed obvious to me that this could be nothing more than coincidence, since the incidence of forest fires was largely dependent upon the weather — and any idea of regularities in rainfall, or the existence of "weather cycles", had been discounted long ago.

The purpose of my talk this morning is to tell how, reluctantly, I came to change my mind. Indeed, I hope to show that our weather in Victoria may not be quite as *random* as many people are inclined to think,-in other words, that there are long term fluctuations in rainfall over the entire State which show certain regularities. These conclusions are not confined to Victoria alone: for in Canada, too, I believe the situation is similar - although there are differences from region to region, proceeding across the Continent.

First, though, a note of warning. In studying rainfall variations over vast areas, like States or Provinces, records must be averaged on a grand scale: and this is a dangerous business. So, we have to be careful. But if it were possible to do this, then we could compare our findings with *other* natural phenomena occurring on a large scale. For example, if there were "cycles" in rainfall, then roughly periodic droughts should be reflected in certain regularities in, say, the incidence of forest fires on the one hand, or in similar variations in the yields of non-irrigated crops - which, also, are clearly affected by drought conditions. In fact, this is what I hope to show in the present talk.

Now, if these proposed "regularities" in rainfall do indeed exist, then questions regarding sun-weather relationships are immediately raised. For, as we all know, there has recently been renewed interest in the idea that global weather is somehow connected with the sunspot cycle. So - despite the fact that this is a most controversial subject, and that no accepted mechanism has been agreed upon whereby some causal connection between solar activity and weather can be postulated - let us begin by *assuming* that such sun-weather relationships are real, and find where this assumption leads.

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[1] Presented at the Symposium on Environmental Consequences of Fire & Fuel Management in Mediterranean Ecosystems, Palo Alto, Calif. Aug. 1-5, 1977.

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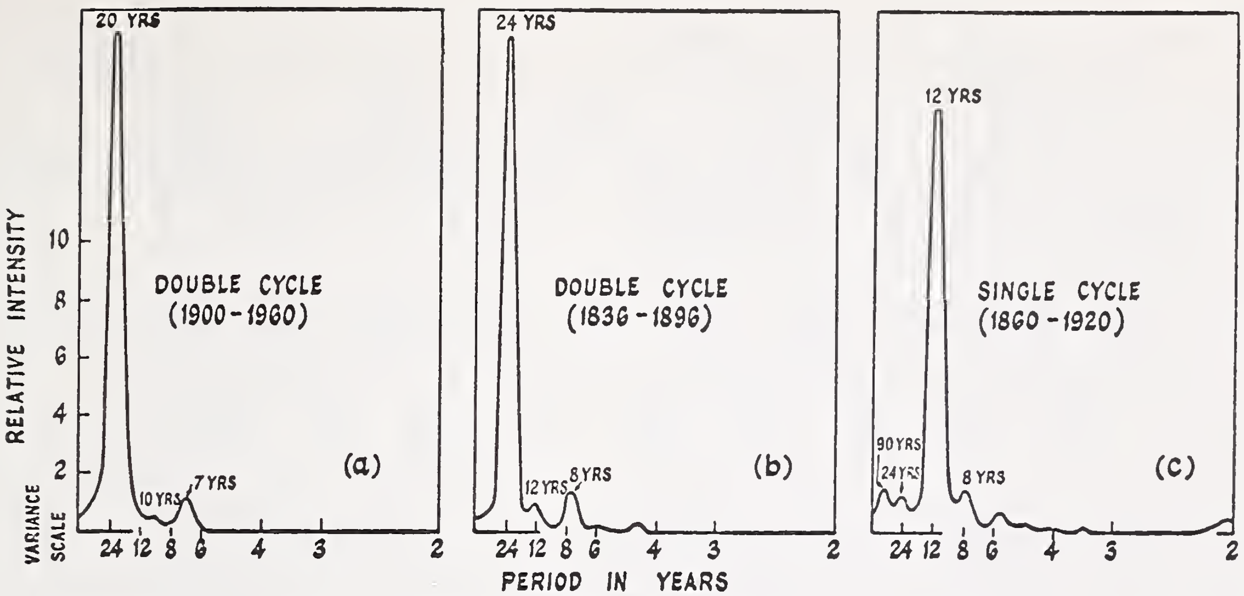

Fig. 1 Power spectra from analysis of yearly-mean sunspot numbers, over time intervals of 60 years as shown.
(a) From 1900 to 1960, the double cycle was little more than 20 years as the major peak indicates : a minor peak, at about 7 years, is clearly suggested.
(b) From 1836-1896, the double cycle was closer to 24 years and the minor peak is now shifted to about 8 years.
(c) For the single cycle from 1860 to 1920 the major peak is at about 12 years : a minor 8 year peak, as in (b), is also evident.

This means, of course, that we must start with the sunspot cycle itself, and see what regularities are apparent there.

THE SUNSPOT CYCLE

The solar cycle has a "period" of about 10 to 12 years - although this is extremely variable, and these limits have often been exceeded in the past. Strictly, it should be thought of as a *double* cycle of about 22 years, since alternate cycles have reversed average solar magnetic field, with the polarity of the spots changed. Reasonable records of solar activity, as measured by sunspot numbers, extend back to the year 1700, although the accuracy of the records before about 1850 may perhaps be questioned.

Simple spectral analysis of yearly mean sunspot numbers (see fig. 1) suggests that solar activity is described not only by the single or double cycles but, in addition, by a further cycle of about 7 years, which is apparently the second harmonic of the double cycle. Probably, there are other periods too – of a much longer term – which are not resolved here.

Harmonic analysis also gives results which are consistent with this view, and figure 2 shows the phases of the curves obtained from such analyses of separate sets of data, each set corresponding to one or two complete double cycles in the sunspot numbers. For simplicity, the curves in Figure 2 have been drawn with *constant* amplitude from 1855 to 1960, but this does not greatly distort the results, except from about 1930 onwards when solar activity showed a marked increase - culminating in the largest sunspot maximum yet recorded, in 1958.

Harmonic analysis further indicates that the amplitude of Curve 1 (for the double sunspot cycle) is about 4 to 5 times greater than that of Curve 3 (the 2nd harmonic) : correspondingly, in analyses of single sunspot numbers the amplitude of Curve 2 is, again, 4 to 5 times greater than that of Curve 3. Higher harmonics seem of minor importance. Indeed, if Curves 1 and 3 and Curves 2 and 3 are summed (assuming that the ratios of the amplitudes are uniformly 4:1 in both cases) we obtain the curves in figure 3. It is apparent that the results provide a close approximation to the *actual* single and double sunspot numbers as given in the records (the dotted curves in Figure 3, beyond 1930, take into account the rise in solar activity from about that time).

Thus, by postulating the presence of the second harmonic we can explain certain odd features of the sunspot cycle. Indeed, although the sun's habits are undoubtedly complex, it seems possible to characterize sunspot activity and provide an approximate description of solar behaviour, in terms of "cycles" of about 22 years (22/1), about 11 years (22/2) and about 7 years (22/3). These periods do of course vary, depending upon

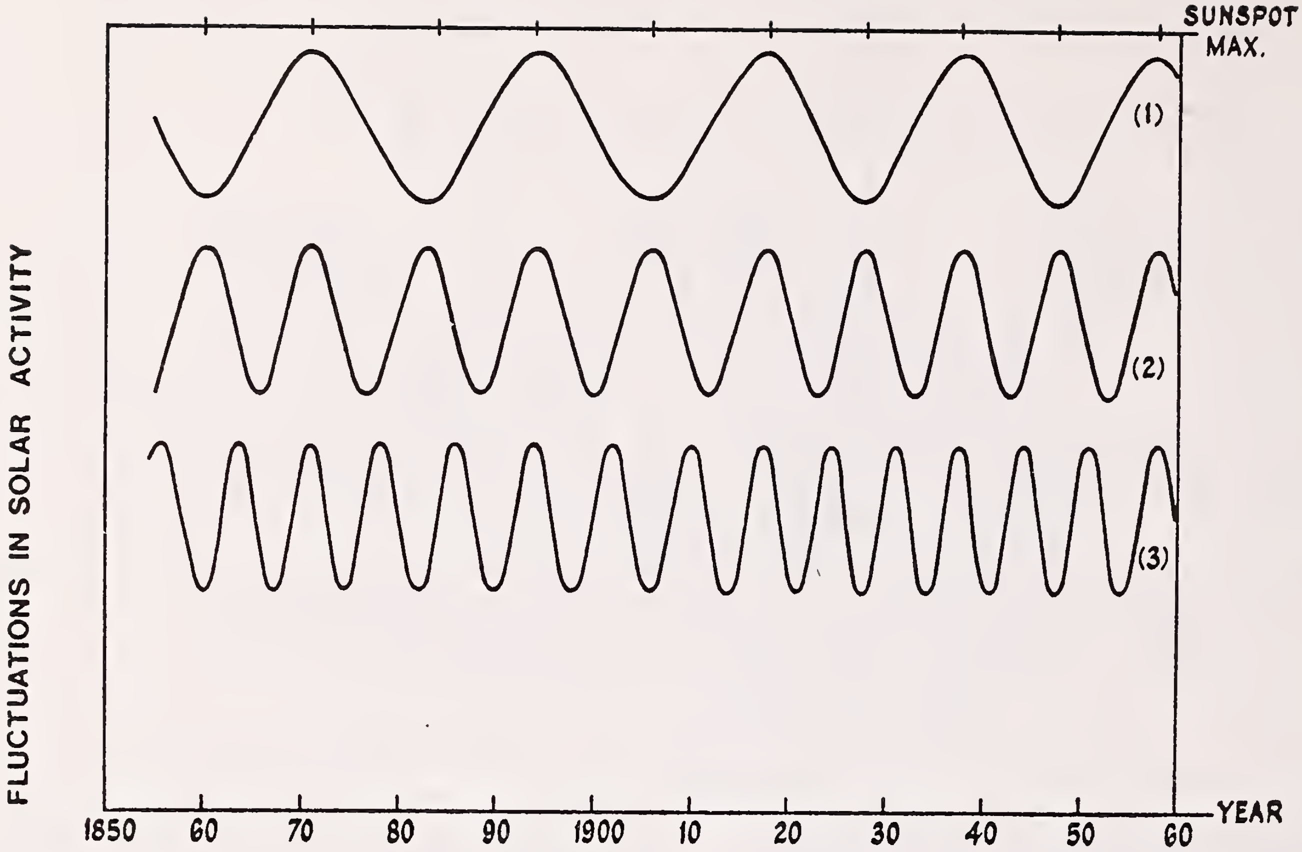

Fig. 2 Harmonic analysis of sunspot numbers and estimated solar cycles from 1855 to 1960.

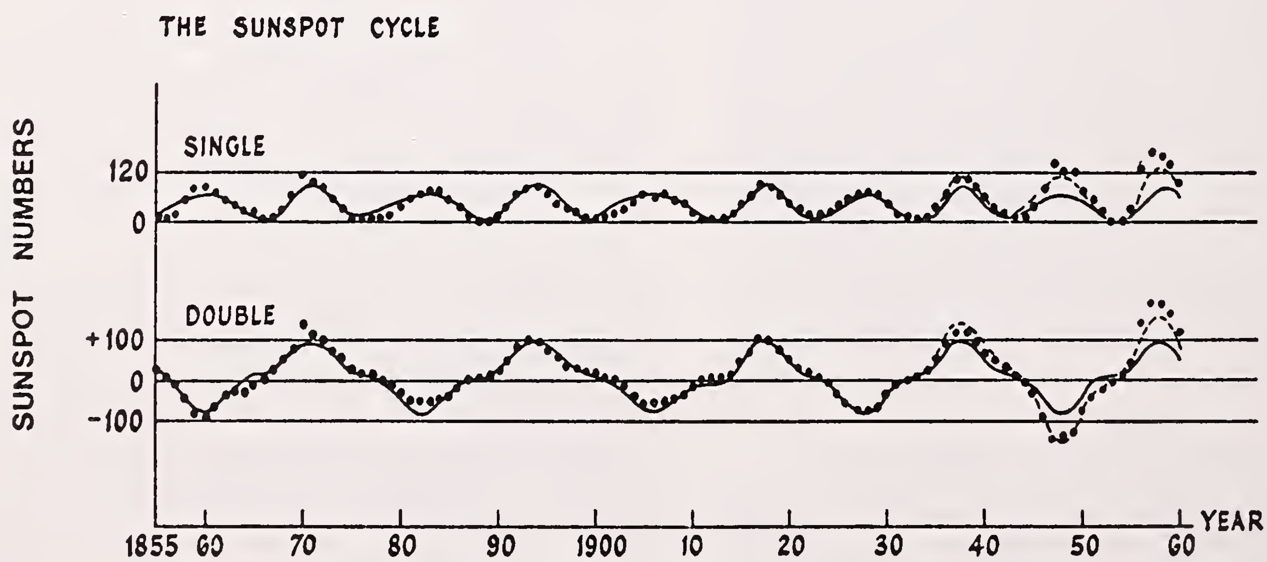

Fig. 3 Representation of the single and double sunspot cycles (1855 to 1960), derived from Fig. 2 by summing curves 2 and 3 and curves 1 and 3 respectively with amplitude ratios of 4:1.

Actual sunspot numbers are as indicated.

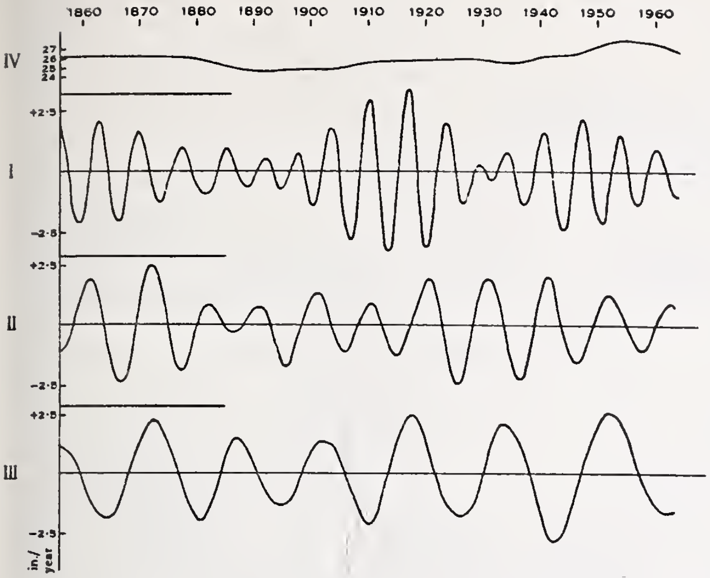

Fig. 4 Computer analysis of annual rainfall figures for Melbourne (1856-1964).

changes in the length of the double sunspot cycle itself, about its mean of ∿ 22 years.

SOLAR ACTIVITY AND RAINFALL

If solar activity and rainfall are indeed inter-related, then there should also be periodicities in rainfall which reflect those listed above for the sunspot cycle. Here I must mention a computer technique which allows us to "tune in" to rainfall periods within the ranges that interest us: in other words, the computer does an exercise in curve fitting and extracts such cycles from rainfall data. (A brief description of the method, essentially one of filter-analysis, is given in the Appendix.)

As an example of how the technique may be used, figure 4 is the result of an analysis of the yearly rainfall figures for Melbourne, the Victorian State Capital. The data have been broken up into four parts, a shifting-mean rainfall, representing variations in the Melbourne average (and including as well any regular fluctuations of very long term), and three additional "cyclic" components comprising a long-term curve, a second with a period of about 10 to 11 years and a third of about 6 to 7 years. The system is so designed that, by adding these four components together, the original data can again be reproduced, although all short-term fluctuations of 5½ years, or less, have been suppressed in the analytical process.

Now, of course, such an analysis doesn't necessarily *mean* anything, for it could be regarded merely as curve fitting - as I have said. So we cannot believe that anything worthy of note has been achieved so far!

Let us now move far away from Australia, to the Canadian Prairies. Figure 5 shows the result for "Swift Current", a town in Saskatchewan, whose rainfall records have been analysed in the same way as Melbourne's above. Curve V is the sum of the other four curves shown, and it is compared with the raw rainfall data from which the analysis was derived. It will be observed that the amplitudes of the "component" Curves I, II, and III vary (as was the case for Melbourne): but, otherwise, they are quite regular. If we study other towns nearby (e.g. Moose Jaw and Regina) we again get results which are almost the same: indeed, the curves obtained are closely in phase with those in figure 5 (although their amplitudes are generally different). This similarity is not too surprising since it is well known that rainfall records for towns which are relatively close tend to show a certain "coherence".

Further analyses, for towns in other parts of the Prairies, yield similar answers - i.e. the curves so produced are still closely in phase with those of figure 5. Indeed, if for each town we draw the curves with an arbitrary *constant* amplitude, the results obtained are virtually the same for *all* the Prairie towns. It is, therefore, easy to produce an artificial "rainfall pattern" which is representative of the Prairies as a whole (see fig. 6) : in other words, the "coherence" of the rainfall data extends over the entire area.

Let us now examine whether there is anything noteworthy about the curves in figure 5, from which we have deduced the curves in figure 6. First, although we could fit somewhat similar curves to sets of random numbers, those fitted curves would not be as regular and, obviously, they would not show coherence from set to set. Secondly, if we turn again to both figures 4 and 5, we find that although the curves marked III have different "periods" (about 16 years in Fig. 4 and about 22 years in fig. 5), those marked I and II are ∿ 6 to 7 years and ∿ 10 to 11 years, respectively, in either figure. The question then arises whether this latter observation tells us anything about rainfall in Australia and Canada, or whether it merely discloses the characteristics of the computer program used?

If figure 6 does reflect real "periods" in rainfall, the minima in the curves must represent tendencies towards drought (even as, conversely, the maxima will indicate times of rain). It is therefore interesting to see if

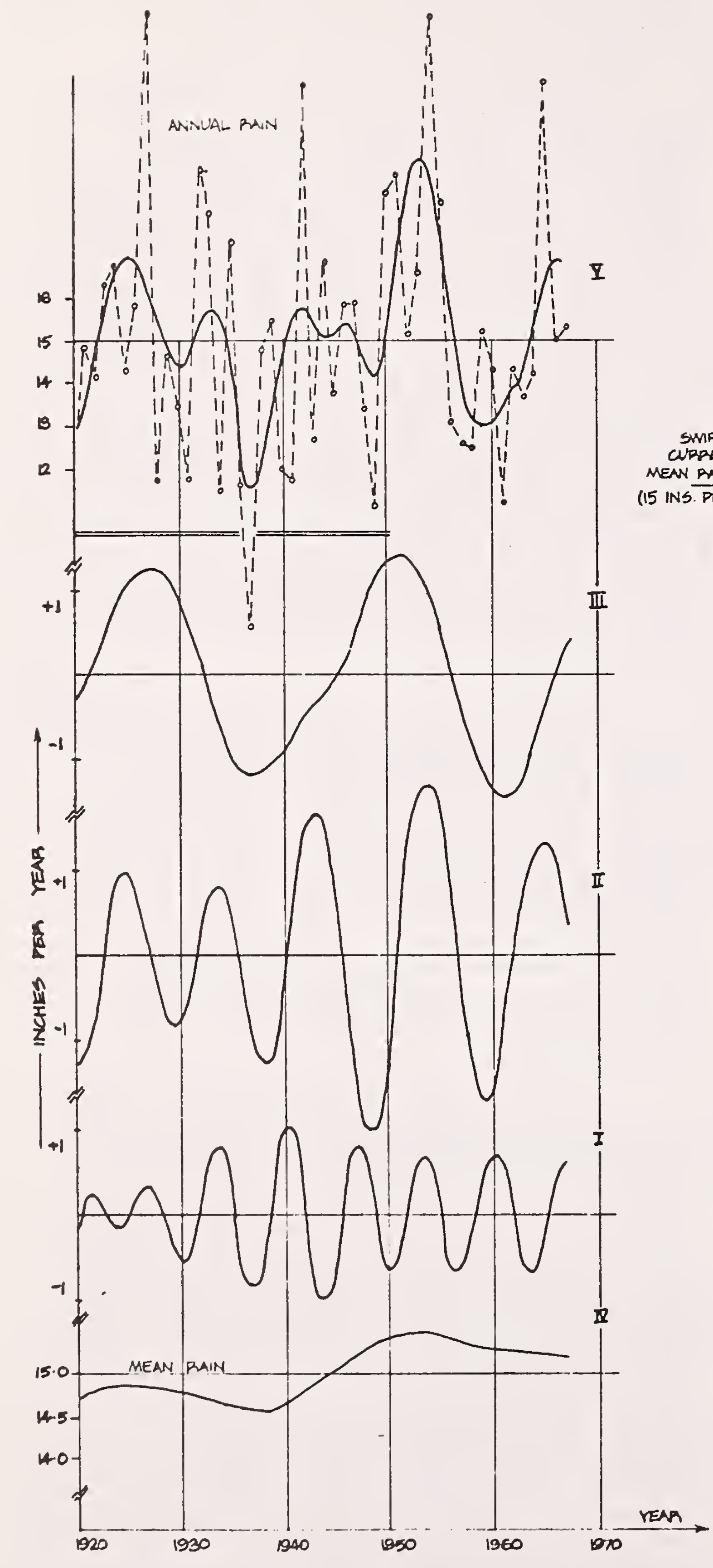

Fig. 5 Analysis of annual rainfall figures for Swift Current (1920-1967) : the computer outputs (I to IV) are as shown. The smoothed rainfall trend (curve V) is the sum of curves I to IV, and is compared with the original records plotted year by year.

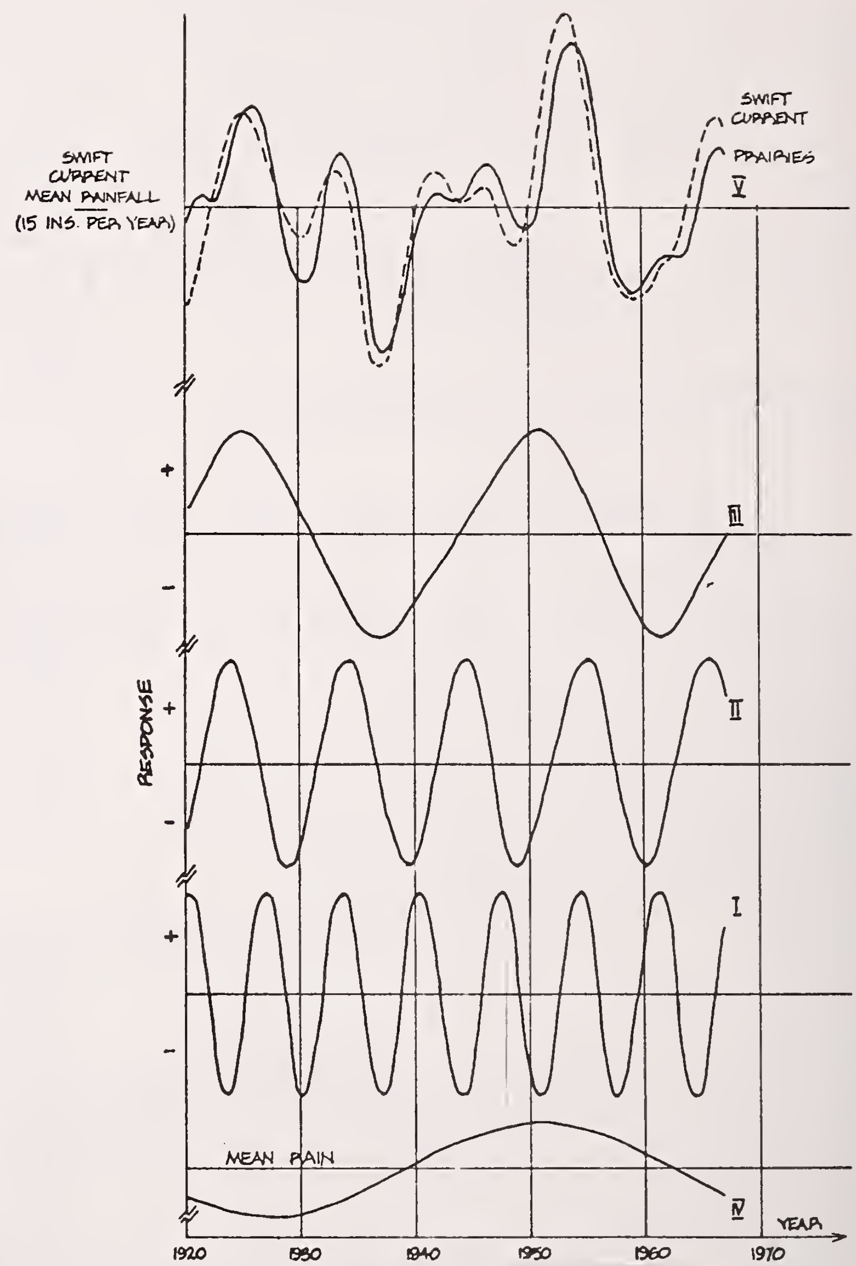

Fig. 6 Rainfall pattern for the Prairies as a whole (1920-1967). Curve V is the sum of curves I to IV, and is compared with the rainfall trend for Swift Current as derived in Fig. 5.

Table 1

FIRE OCCURRENCE IN PRAIRIES AND BRITISH COLUMBIA

- (area burnt : millions of acres) -

"10/11 year" period (From Fig. 6)	Manitoba & Saskatchewan	Alberta.	British Columbia	"7 year" period (From Fig.6)	Manitoba & Saskatchewan	Alberta	British Columbia
'19	1919 (5 mill)	1919 (1 mill)		'23	1924 (½ mill)	1922 (> ½ mill) 1924 (> ½ mill)	1922 (1½ mill)
'29	1928/9 (5 mill)		1929 (1 mill)	'30/1	1930 (1 mill)	1931 (> ½ mill)	1931 (1 mill)
				'37/8	1936/7 (4 mill)	1937/8 (2½ mill)	1938 (3/4 mill)
'40	1940 (1½ mill)	1941 (1½ mill)		'44		1944 (3/4 mill)	
'49	1948/9 (1½ mill)	1949 (1½ mill)		'50		1950 (> ½ mill)	1950 (1 mill)
				'57	1958 (>3/4 mill)	1956 (> 1½ mill)	1958 (2 mill)
'60	1960/1 (5½ mill)		1961 (1½ mill)	'64	1964 (2 mill)		
'69	1970 (1½ mill)	1968 (1 mill)		'71			1971 (1 mill)

we can compare these curve-minima with the incidence of forest-fires as provided by the Prairies fire statistics, (remembering that major forest-fires are indicative of drought situations). In this way it should be possible to determine whether our derived weather-pattern is at all valid, or whether it is merely an artifact introduced by the particular form of computer analysis adopted in the rainfall studies.

The results are shown in table 1, where it may be seen that there is, indeed, very good correspondence between the minima in the Prairies curves and the incidence of forest-fires. Evidently there are two distinct patterns of fire-occurrence, for disastrous fires seem to occur in roughly cyclic fashion with periods of about 10 to 11 years and about 7 years. In the Prairie Provinces (and also in British Columbia), there are *no other* bad fire-years besides those shown[3/]. This strong agreement with the rainfall pattern is worthy of note, as it will be recalled that all short-term fluctuations of 5½ years, and less, have been suppressed in analysing the rainfall data.

Since the fire-years themselves display such obvious patterns, this suggests that the "tendencies towards drought" indicated by the minima in the computer curves of figure 6 correspond closely with *actual* droughts. Furthermore, if we repeat the same procedure in the Eastern Canadian Provinces, (Ontario, Quebec and the Maritimes), the strong agreement persists: for although the fire-years are chronologically different from those in the West, they follow the same kind of periodic pattern of rainfall, with droughts (and bad fires) actually occurring about every 10 to 11 years and about every 7 years. The implication is that the periods in question may be of some importance in characterizing Canadian weather across the entire Continent.

The rainfall pattern for Ontario (cf. fig. 7) throws further light on the hypotheses being proposed in this paper, for we see that there is correlation between the *peaks* of the curves shown and the sunspot cycle. Indeed, it will be observed from Curve E in figure 7, which delineates the rainfall trend, that times of

[3/] In these bad years forest-fire losses are of the order of 1 million acres, in comparison with an "average" year in which it is unusual for more than 100,000 acres to be burnt.

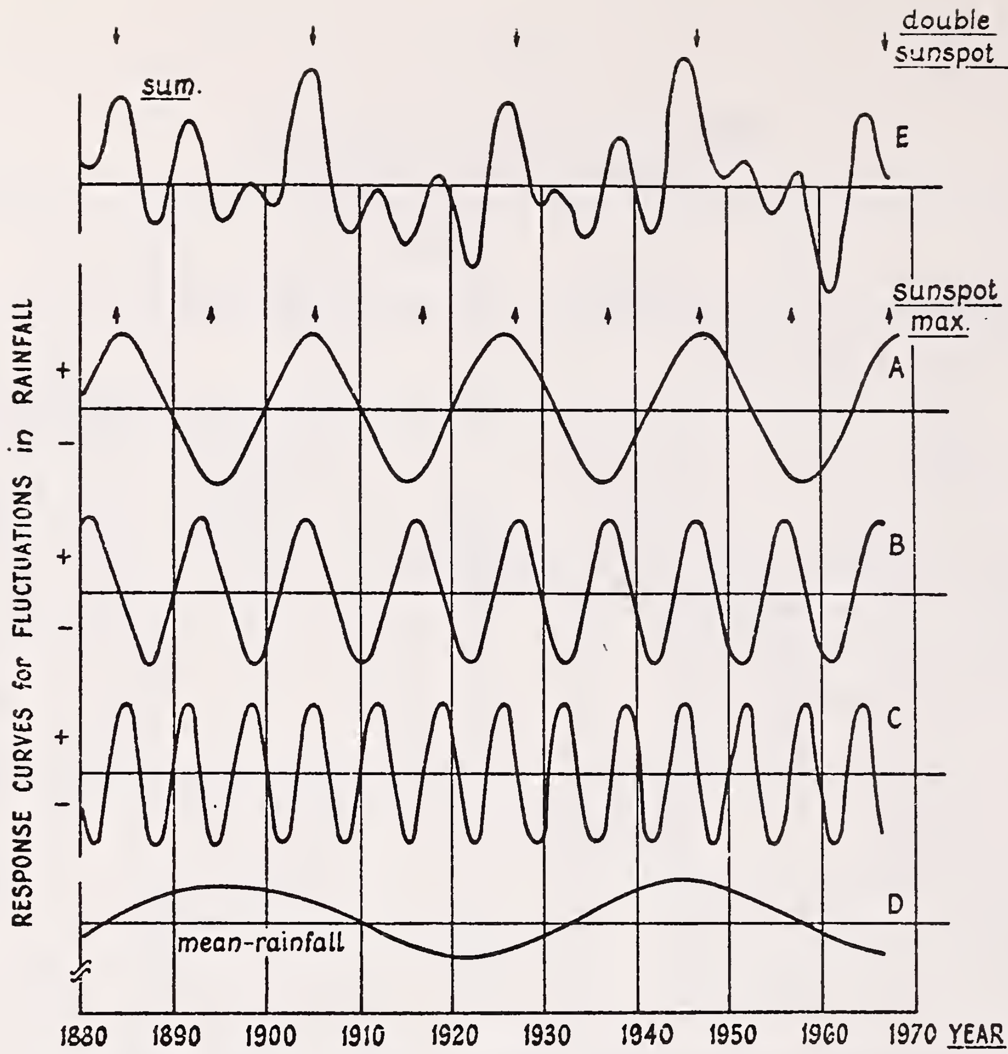

Fig. 7 Rainfall pattern for Ontario (1880-1967). Curve E is the sum of the four curves A, B, C and D. Years of maximum sunspot activity are shown by arrows.

major rainfall, in Ontario as a whole, are very closely in phase with the double cycle (with sunspot maxima in 1884, 1906, 1928, 1947 and 1968). Furthermore, careful inspection reveals that the relevant maxima of the curves A, B and C are almost exactly in phase with individual sunspot maxima - as indicated by arrows in the figure. Thus it seems our earlier assumption, that there are variations in rainfall which are roughly periodic and geared to solar activity, could be true.

AUSTRALIAN WEATHER

But what about Australia?

You will recall that crop-yields were mentioned earlier. The yield from any farm is, of course, dependant upon a variety of factors (good management, use of fertilizers, time of spring rains and follow-up rains etc.). But one very important variable is *total* rainfall - for below a certain critical amount of rain, particularly in marginal areas in Australia, crop-yields per acre fall rapidly. So it is interesting to examine Victorian wheat and oat yields, year by year (in bushels / acre), which are given in the State Year-Books, and compare these *raw data* with the "weather pattern" as derived for Victoria in exactly the same way as it was for the Canadian Provinces

Table 2

OATS AND WHEAT YIELD IN VICTORIA

"Drought-Years" in Figures 6 and 9 vs. years of *Poor Oats* and *Wheat Yield*.

SHORT TERM (6-7 year pattern)		MEDIUM TERM (10-11 year pattern)		LONG TERM (+ 16 year pattern)	
"Drought-Years" from Curve C in Figs. 8 & 9	Years of poor Crop-Yield	"Drought-Years" from Curve B in Figs. 8 & 9	Years of poor Crop-Yield	"Drought-Years" from Curve A in Figs. 8 & 9	Years of poor Crop-Yield
		1885	*1885*		
1888	*1888*				
1895	*1895*	1896	*1896*		
1902	*1902*				
1907	*1907* ←	1906			
1913/4	*1914* ←	1914/5		1912	*1911*
1919	*1919*				
1925/6	*1925* ←	1925			
				1927	*1927*
1932	-				
1938	*1938* ←	1937			
1944	*1944* ←			1943	*1943*
1952	-	1948	*1948*		
1959	*1959*	1957	*1957*	1961	*1961*
1965	*1965*	1967	*1967*		

Arrows join closely corresponding years

The results are given in figures 8 and 9 and in table 2. Observe in table 2 the close correlation between the years of poor oats and wheat yield and "drought years" as indicated in the Victorian rainfall pattern, (i.e. the minima in curves A, B and C in figs.8 and 9). Yields for barley and hay provide exactly the same answer, for being non-irrigated crops they, too, grow poorly in dry conditions. Thus, the evidence suggests that there is a discernible *pattern* (not attributable to computer curve-fitting) in the occurrence of bad drought-years in Victoria. Most of the years listed in table 2 were particularly dry when, over a very large proportion of the entire State, there was a rainfall deficit of 20% or more[4].

Strictly, of course, there is no satisfactory definition of "drought", for it is difficult to specify drought situations accurately in terms of universally agreed criteria. Nevertheless, by using the yields of non-irrigated crops as "drought indicators", we have shown above that the various minima in the curves A, B and C in figures 8 and 9 correspond closely with all those "drought years" in which crop yields were low[5] - even as, for the Canadian Prairies, the minima in the Prairies rainfall curves corresponded to the years of disastrous forest-fires.

In fact, practically all Victorian droughts since 1885 have been accounted for in the analysis (see table 2); and the strong agreement shown is noteworthy when we recall, once more, that all short-term rainfall fluctuations with periods less than 5½ years have been suppressed by the computer technique. Thus, the so-called "weather patterns" which emerge from our analysis of rainfall, (and which might be dismissed by the sceptic as the result of a mere exercise in curve fitting), do seem to have some factual foundation. Indeed, serious droughts in both

[4] In precisely the same way, the above procedure can be applied to a study of wheat yields on the Canadian Prairies: again there is excellent correlation between "years of poor wheat yield" and the minima in the Prairies rainfall curves as illustrated in figure 6.

[5] Furthermore, it follows that if the raw crop-yield data are processed using the computer technique, then the crop-yield patterns will very closely resemble the Victorian rainfall pattern. It may be seen from figures 8 and 9 that this is, indeed, the case.

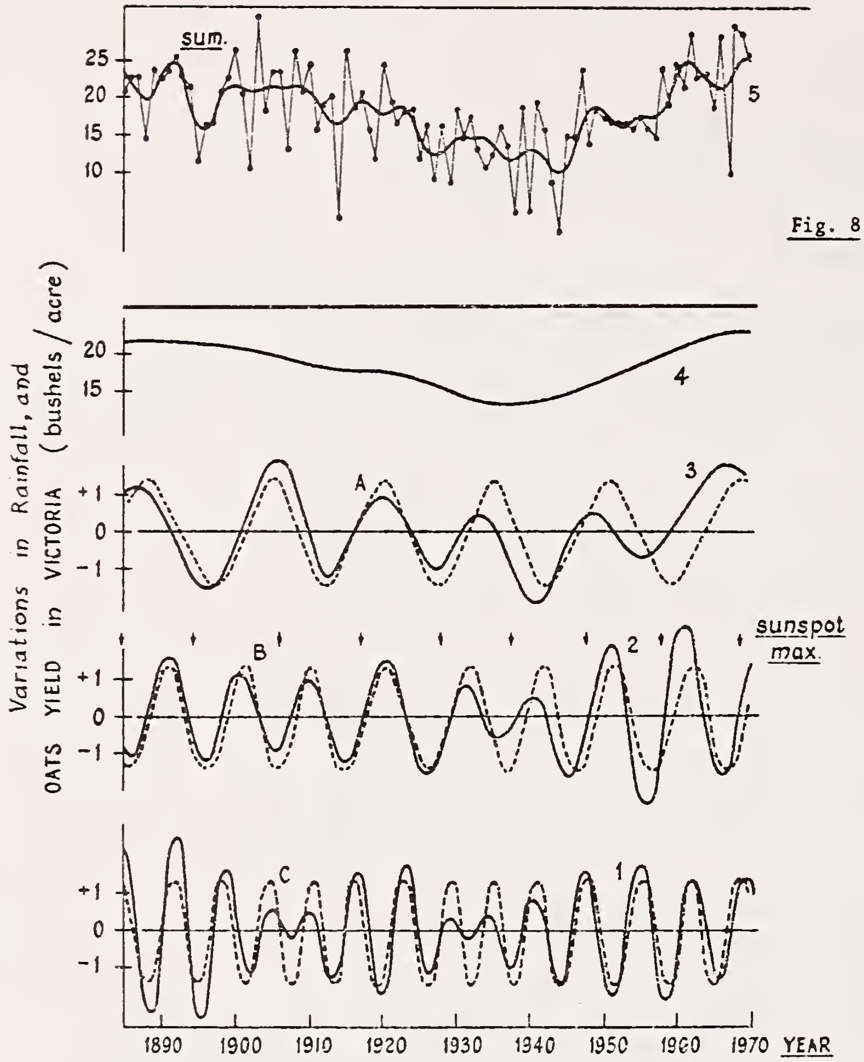

Fig. 8 Rainfall and oats-production in Victoria (1885-1970). The *broken* curves A, B and C typify the Victorian weather pattern (drawn with an arbitrary vertical scale) and represent quasi-periodic fluctuations in rainfall over the State.
Annual yields of oats (bushels/acre) are as indicated. Curve 5, which illustrates the trend in oats production, is the sum of the *continuous* curves 1, 2, 3, 4 as derived by computer analysis of the annual oats figures. Arrows denote years of maximum sunspot-activity.

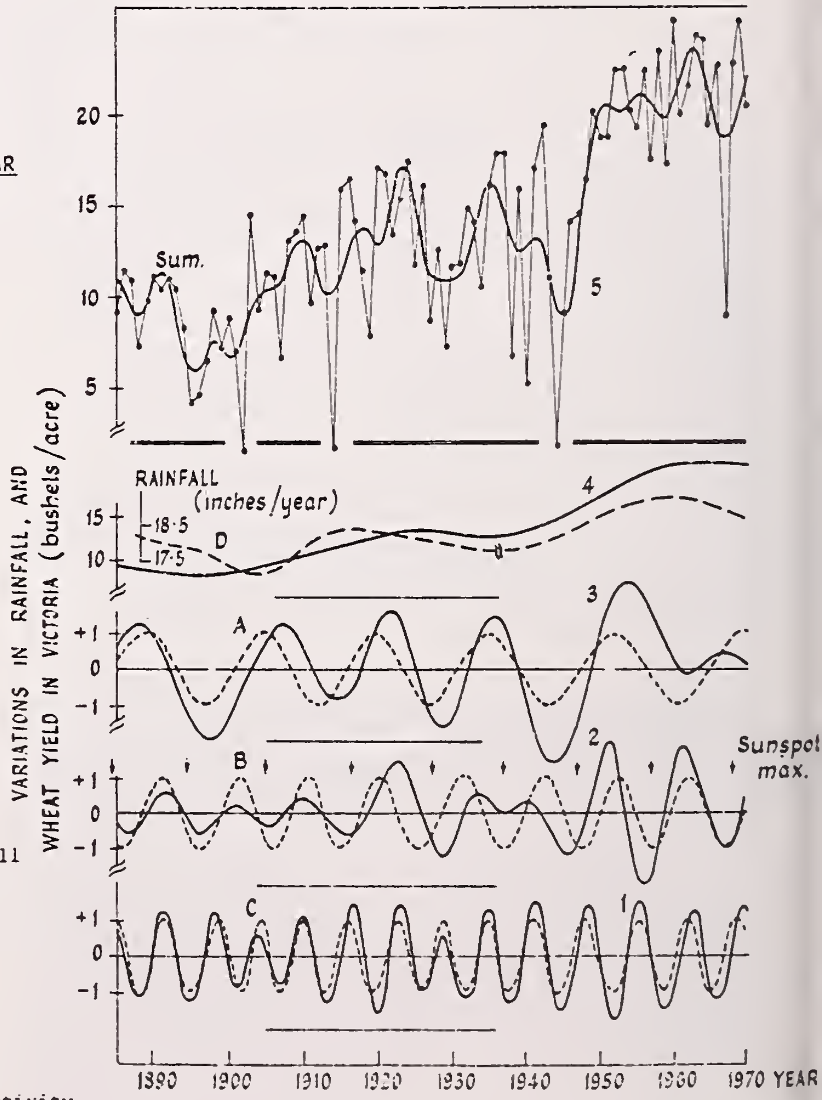

Fig. 9 Rainfall and wheat-production in Victoria (1885-1970). Broken curves A, B and C, representing the Victorian weather pattern, are the same as those in Fig. 8. Curve D (dashed lines with separate scale) indicates the shifting-mean rainfall in the major wheat-growing areas.
Annual wheat yields are as shown. As in Fig. 8, curve 5 (illustrating trends in wheat production) is obtained by summing curves 1, 2, 3 and 4, derived by computer analysis of the annual wheat-yield data. Note that curve 4, the shifting-mean in wheat production, approximately follows the trend in curve D. Arrows denote years of maximum sunspot activity.

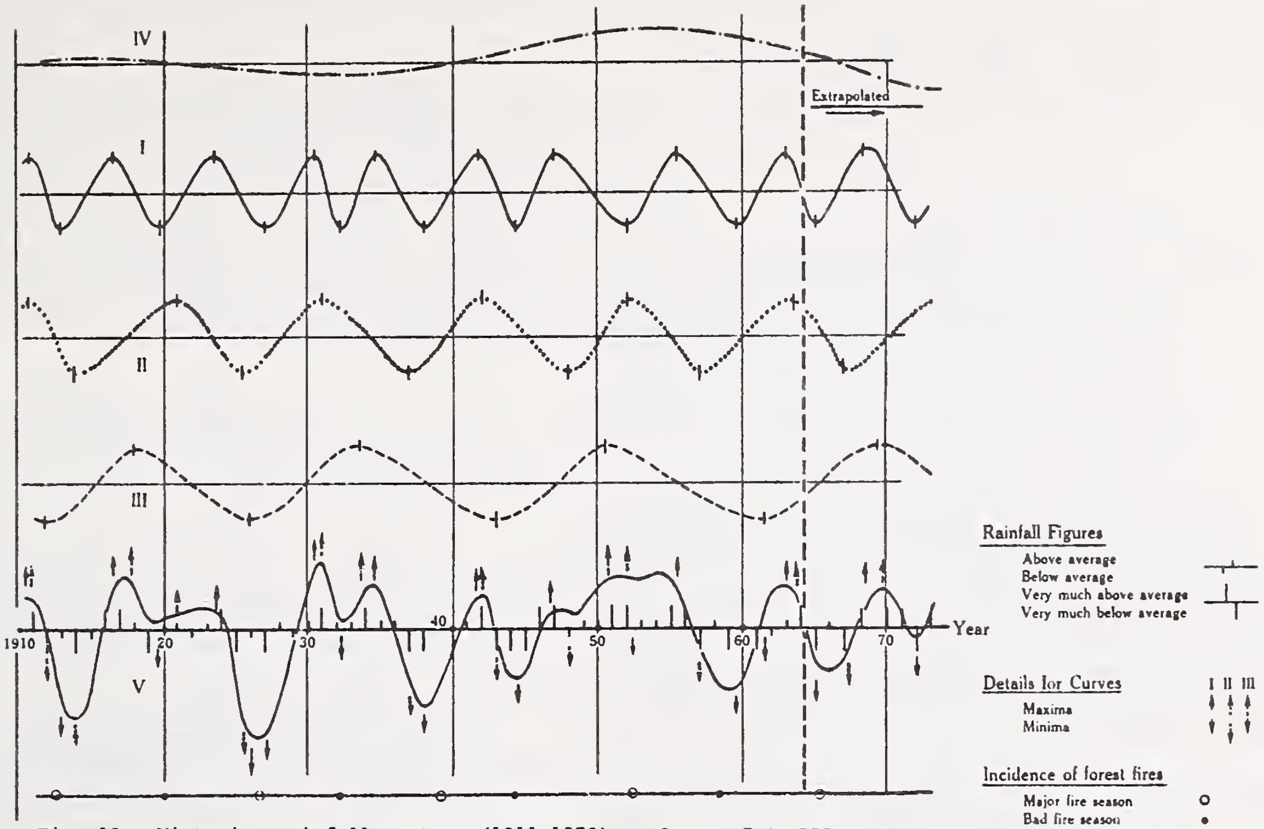

Fig. 10 Victorian rainfall pattern (1911-1973). Curves I to III are the same as curves A, B and C in Figs 8 and 9, but are drawn on an expanded scale. Curve V, the sum of curves I to IV, represents trends in Victorian rainfall and comparison is made with rainfall figures derived from District records: the pattern is extrapolated beyond 1964. (Maxima and minima of curves I to III are indicated by arrows.) Victoria's most notable fire-seasons are as shown.

Canada and Australia apparently occur with just that kind of regularity to be expected on the basis of our earlier hypothesis regarding weather and the sunspot cycle. To reinforce this claim, it may be noted that curve B of the Victorian weather-pattern shown in figures 8 and 9 indicates strong correlation with the sunspot cycle (cf. also, the Ontario pattern in fig. 7, which has already been discussed).

If the Victorian rainfall pattern is presented separately, other notable features are apparent (see fig. 10). For example, it may be seen that the quasi-periodic occurrence of drought-years - in which rainfall was very much below average - is complemented by years when rainfall was very much above average - such wet periods being shown by the *maxima* of the curves. Furthermore, bad forest-fire seasons in Victoria closely follow the minima of curve 1, *alternate* minima being years of major fire-seasons (1913, 1926, 1939, 1952 and 1965, as mentioned in the Introduction), with the intermediate years being those of minor fire-seasons.

Of particular interest is the fact that the Victorian pattern was established, originally, by analysing rainfall records which extended only to the end of 1964. If, as is claimed, the curves so obtained are not merely a product of curve fitting but have some physical significance, then it should be possible to project them into the future. Indeed, simple extrapolation of the curves allows some estimation of rainfall trends *beyond* 1964, and the resulting predictions have been successful. Thus, in figure 10, the droughts of 1965, 1967, 1972 (and 1976), together with the corresponding wet periods, are clearly indicated. In other words, the pattern characteristic of rainfall trends up to 1964 seems to have remained unchanged to the present time[6].

[6] Similarly, to give a single Canadian example, forward predictions from Provincial rainfall figures to the end of 1967 strongly suggested the major drought which has, in fact, been experienced in the Prairies and British Columbia in 1976/7.

Should this same behaviour continue, the period from 1976 to approximately 1980 may well be drier than average. This claim, if correct, could be of some importance to farmers.

DISCUSSION AND CONCLUSIONS

Analysis of weather records in Canada and Australia suggests that there are, in both countries, fairly regular long-term fluctuations in rainfall which affect wide areas although they may be manifest in varying degree from place to place. The "rainfall patterns" I have described are an attempt to represent these fluctuations: they also appear to account for an appreciable proportion of rainfall variability. I have tried to confirm the validity of these patterns by showing that forest-fires and years of poor crop-yield are coincident with the "drought situations" which the patterns imply. Furthermore, there seems to be a close connection between the proposed "patterns" and the double sunspot cycle.

Rainfall *predictions* based upon these premises, have had some measure of success. In this respect, however, the erratic nature of the sunspot cycle presents difficulties; for to predict weather in terms of the sun's future behaviour presupposes that solar activity can itself be accurately predicted - which is not yet the case. For most of this century the double sunspot cycle has been almost exactly 21 years, but recently the cycle has lengthened: thus predictions which rely on past regularities will no longer be appropriate, and the "weather patterns" may have to be adjusted slightly to accommodate observed changes in solar behaviour.

The rainfall patterns can, of course, be projected backwards in time, as well as forwards. When this is done, past "droughts" which are delineated by the patterns correspond very well with known bad fire-years as mentioned in historical records, in both Canada and Australia. But this procedure only affords us an extended perspective, from the *present* into the *past* of less than 150 years,-though it may be possible to go back further in time by appealing to tree-ring records. [7]

[7] Early claims were made of correspondences between variations in tree-ring widths — which are weather dependent — and the sunspot cycle (A.E. Douglass (1914) in "The Climatic Factor", Carnegie Inst. Wash. Publ. 192, 101): however, more recent evidence does not seem to support such conclusions (cf. H.C. Fritts (1976) "Tree Rings and Climate", Academic Press). But the situation is not clear-cut, for there are also good indications of the importance of the sunspot cycle over long periods in the past (see, for example, G. Sirén (1972) "Climate in the Past and in the Future", Acta Univ. Oul. A3, Geol.1, 351).

In summary, we have explored the possibility of a relationship between solar activity and weather. Nevertheless, unless a plausible mechanism is forthcoming whereby sunspots and global rainfall are obviously linked, any further systematic investigation of this problem will clearly require complex statistical analysis to substantiate the present findings.

APPENDIX

THE COMPUTER SYSTEM

The filter program was developed by Dr. E.G. Bowen F.R.S., former Chief of the CSIRO Division of Radiophysics. It was originally written for the CDC 3200 computer (Bowen, unpublished work).

In analysing rainfall records, the program subjects them to four separate filters - a low-pass filter (moving average), and three band-pass filters having nominal periods of about 20, 10 and 7 years. Each filter allows the passage of signals within a predetermined frequency range, but rejects all others. A diagrammatic representation of the system is given in Figure 11.

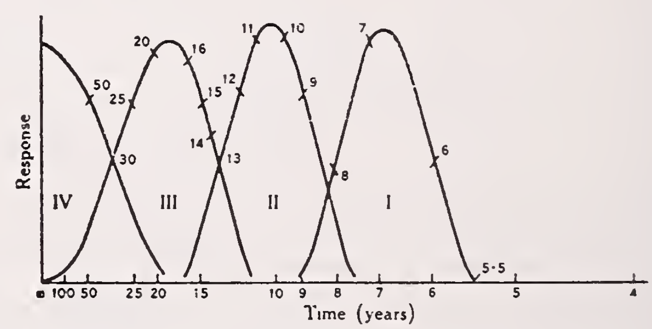

Fig. 11 Diagrammatic representation of the computer system: the response curves of filters I, II, III and IV are as shown.

The four filters overlap: filter I accepts periods from $5\frac{1}{2}$ years to 9 years; filter II accepts periods ranging from $7\frac{1}{2}$ years to 16 years; while filter III accepts those from 11 years to > 50 years. Filter IV accepts all periods beyond 20 years, with high acceptance beyond 30 years, and it therefore reproduces what is essentially a shifting-mean rainfall.

The combined response of all four filters together is reasonably flat beyond about $6\frac{1}{2}$ years, and only those fluctuations with periods shorter than $5\frac{1}{2}$ to 6 years are rejected by the system. Thus, after the long-term periods

have been extracted from the data, only short-term cycles and random oscillations remain. When the four filter outputs are added together again, the resultant smoothed-curve provides a good representation of the original records, and clearly illustrates rainfall trends.

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2051

FEATURES OF THE SUNSPOT CYCLE[1/]

R. G. Vines

Abstract: Analysis of sunspot numbers suggests the presence of a hitherto unsuspected component in the data, having a period of approximately 7 years. Although the sun's behaviour is complicated, this result helps to explain certain well known features of solar activity: it seems likely that the period in question is the second harmonic of the Double sunspot cycle.

Key words: Sunspot cycle, spectral analysis, solar activity.

The irregular nature of the sunspot cycle has long been known, and numerous attempts have been made to analyse sunspot numbers, which form a quasi-periodic series. Although these past attempts have generally met with little success, recent power-spectrum studies by Cole (1973) show considerable promise, and indicate ways in which a model of solar activity might ultimately be formulated.[2/] In this connection a further programme of spectral analysis has yielded an interesting result, which strongly suggests that a 7 to 8 year period may be present in the sunspot-number data.

Figures for both the Single and Double sunspot cycles have been studied, using the annual means as listed in World Weather Records (1967) in which data extend from the 18th Century up to 1960: a review of the data is given by Waldmeier (1961). To obtain "double sunspot" numbers, the "even" cycles were inverted in the conventional way (Bracewell 1953) in order to take account of the changed polarity of the sunspots in successive cycles.

The standard computer program used in the present analysis was kindly provided by Dr. Ian James of CSIRO. A typical result is seen in figure 1a, where the power spectrum of the Double cycle from 1900 to 1960 is shown (with three-point smoothing, as recommended by the World Meteorological Organization - 1971).

1/Short paper contributed in conjunction with the presentation on "Fire and Flood Cycles - past and present", at the Symposium on Environmental consequences of Fire and Fuel Management in Mediterranean Ecosystems, Palo Alto, Calif. Aug. 1-5, 1977.

2/There have, of course, been lengthy intervals in the past when solar activity was apparently very small - e.g. from about 1650 to beyond 1700 (cf. Eddy 1976), a period which happens to coincide with the "Little Ice-Age".

During the present century the Double cycle has been little more than 20 years, and the expected strong 20 year peak is evident; however, the spectrum also exhibits a lesser peak at about 7 years (cf. Hill (1977), and the earlier work of Cole (1973)), and another at ∿ 10 years which is barely perceptible.

Last century the Double sunspot cycle was closer to 24 years, and spectral analysis of the corresponding figures shows this clearly - as may be seen in figure 1b where the spectrum for the years 1836-1896 is presented. It is interesting to note that the lesser peak of figure 1a has now been shifted to about 8 years, and the accompanying minor peak is at 12 years (two further, short-term peaks of doubtful significance are also evident).

For comparison another spectrum is given in figure 1c - this time for single sunspot numbers from 1860 to 1920. The Single cycle averaged 12 years during this period, as the major peak in figure 1c reflects. But a small peak at 24 years is still registered and the peak at 8 years, which was present in figure 1b, remains.[3/]

To summarise, the Double sunspot cycle and its first two harmonics were normally present in all the spectra studied: last century the periods in question were approximately 24 years, 12 years and 8 years, whilst this century (until 1960) they have been closer to 20 years, 10 years and 7 years. It is noteworthy that spectra for the Double sunspot cycle show the small peak corresponding to the single cycle - and vice versa.

3/There is also some slight evidence of a very long-term period of the order of 100 years (of which there is a hint in figures 1a and b, though swamped by the major double sunspot peak): and there are, as well, various minor indications of short-term cycles which are possibly higher harmonics.

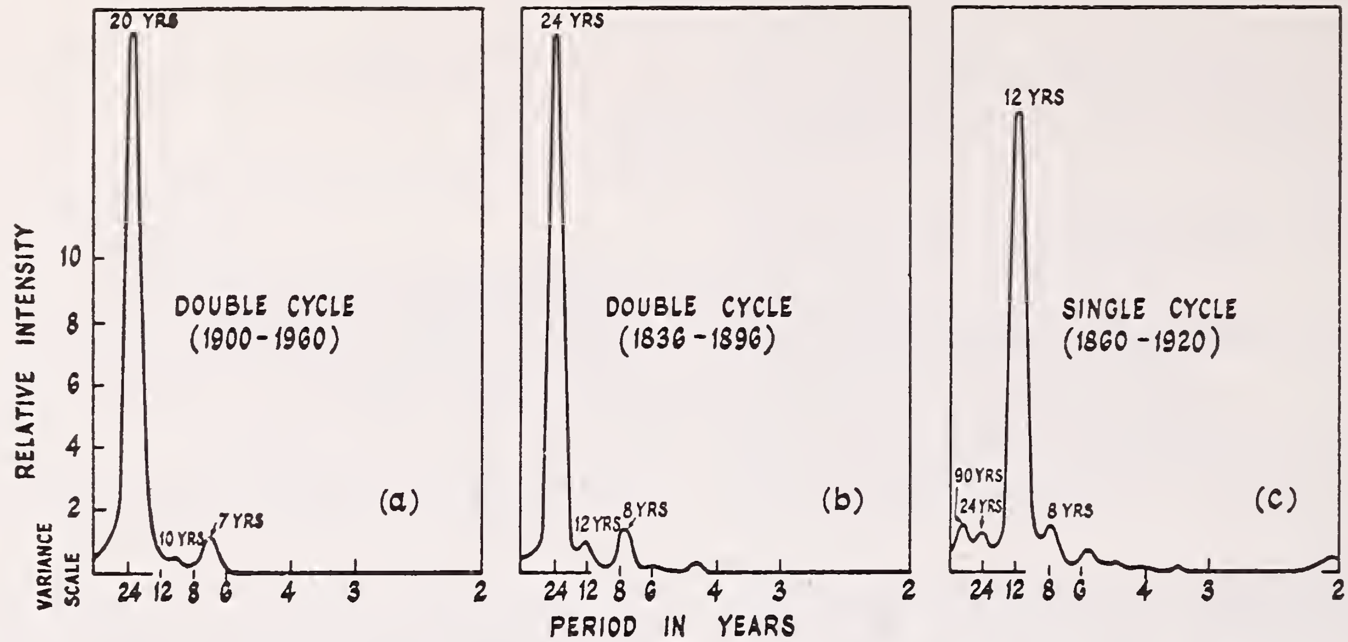

Fig. 1 Power spectra (with three point smoothing) from analysis of yearly-mean sunspot numbers. Over each of the 60 year intervals shown the sum of relative variances is 60, or 100%.

Furthermore, it is of interest that the second harmonic, of 7 to 8 years, is apparent in both sets of spectra.

The sunspot cycle is, of course, extremely complex, and it is recognised that this simple investigation does not resolve numerous other spectral peaks which may be present. However, harmonic analysis has confirmed the general conclusions outlined above and, using that technique, the amplitudes and phases of the individual cycles have been established. Separate sets of selected data were analysed, each set corresponding to one or two complete Double cycles in the sunspot numbers. Such a procedure allowed for the known variations in period of the Double cycle during the last 100 years. In this way curves 1, 2 and 3 in Figure 2 were constructed, (referring to the total time interval from 1855 to 1960): Curve 1 represents the behaviour of the Double sunspot cycle (the fundamental), Curve 2 that of the Single sunspot cycle (the 1st harmonic), while Curve 3 describes the 2nd harmonic. Higher harmonics, though sometimes significant, were rarely reproduced consistently in the various analyses, and it was only the 2nd harmonic (curve 3) that persisted, in conjunction with curves 1 or 2.

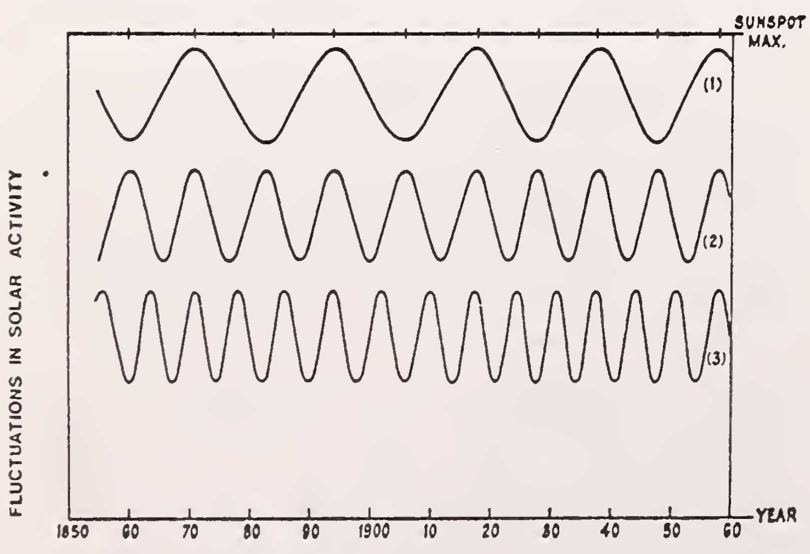

Fig. 2 Estimated solar cycles (1855-1960)

In order to provide simplified parameters, the curves in figure 2 have been drawn with a constant amplitude. This does not greatly distort the results except in those cases when solar activity is appreciably enhanced.[4] It was found that the amplitude of curve 1 (for the Double sunspot cycle) was usually 4 to 5 times greater than that of curve 3 (the 2nd harmonic). Similarly, in the case of the Single cycle, the ratio of the amplitudes of curves 2 and 3, again, was between 4 and 5.

Next, the curves were summed, using the specific assumption that the ratios of the amplitudes were uniformly 4:1, - the sum of curves 1 and 3 relates to the Double cycle, whilst that of curves 2 and 3 relates to the Single cycle. The results obtained provide a close approximation to the *actual* double and

[4] For example, solar activity showed a marked increase from about 1930 onwards, the culmination being the largest sunspot maximum ever recorded, early in 1958. Correspondingly, the amplitudes of all three curves rose significantly during this time.

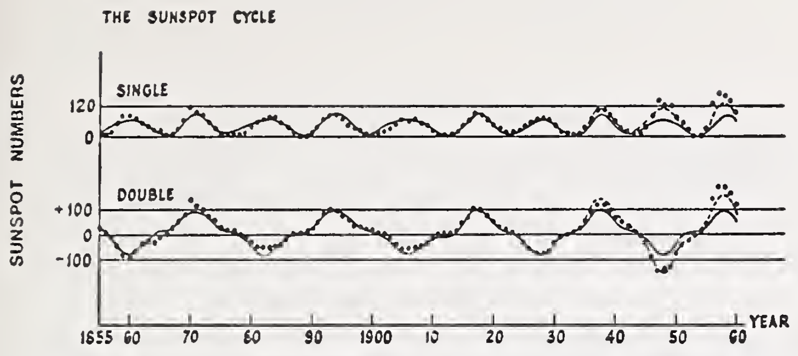

Fig. 3 Representation of the Single and Double sunspot cycles (1855-1960) as derived from Fig. 2, and obtained by summing curves 2 and 3, and curves 1 and 3 respectively - with amplitude ratios of 4:1. Actual sunspot numbers are as indicated.
(The dotted curves beyond 1930 refer to a time of increasing solar activity: see text).

single sunspot numbers, as is shown in figure 3. (Here the dotted curves beyond 1930, with their increased amplitudes, take into account the rise in solar activity from about that date). This remarkable agreement is only slightly improved if the very minor contributions, of curve 2 to the Double sunspot cycle and of curve 1 to the Single sunspot cycle, are included (cf. the details mentioned in connection with figures 1a. b and c). For the purposes of the present analysis, these may be discarded.

It seems therefore that the sunspot-number data contain an important 7-8 year component which has hitherto been overlooked. Indeed, if obvious implications are drawn from the conjunction of curves 2 and 3 in Figure 2, some well known but puzzling features of the *Single* cycle are readily explained:-

Viz † 1. The rise from sunspot minimum to sunspot maximum is normally more rapid than the fall from maximum to minimum.

† 2. There is a tendency for high and low maxima to alternate, - a high maximum usually being followed by a lower one, and then a high one again. (It is evident that curves 2 and 3 are in phase only at alternate maxima).

Similarly, the overall shape of the Double sunspot cycle curve in figure 3, from 1855 onwards, is readily understood in terms of the characteristics of curves 1 and 3 (figure 2) - though it must be pointed out that, whereas curve 3 in conjunction with curve 2 relates to sunspot *numbers*, in conjunction with curve 1 sunspot *polarities* are more probably implied.

A study of early data from 1775 to 1850 yielded comparable results, although the pattern observed was not quite so clear-cut, since the sunspot records indicate more erratic solar activity. One particular feature should, however, be mentioned. The Single sunspot cycle from 1830 to 1837 was such that the 1837 maximum was not a low one, despite the fact that it fell between two *high* maxima in 1830 and 1848 (cf. † 2 above). Interaction of this short 7 year variant with another cycle of ∿ 7 years would produce 3 successive high maxima, (as was actually the case). Alternatively, any sudden increase in the amplitude of the proposed 7 year component would achieve the same result. In any event, a cycle of ∿ 7 years clearly participated in this unexpected behaviour.

These indications of an approximately 7 year period in sunspot activity relate to the earlier work of Abbot (1963), who observed periodic variations in the solar constant and maintained that the periods in question were all harmonics of the Double sunspot cycle. Although Abbot's work has been discounted in recent years, certain aspects of his claims might well be reexamined in any further research on sunspot phenomena.

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ABORIGINAL USE OF FIRE[1/]

Homer Aschmann[2/]

Abstract: Prehistoric man's presence resulted in a greatly increased frequency of fires over those resulting from natural causes in regions of mediterranean climate. Deliberate burning to improve hunting, food plant growth or pasture could be as often as annual and maintain a grass cover. At its discovery in 1420 uninhabited Madeira had a forest cover denser than any found in inhabited Mediterranean climate areas of comparable climate.

Key words: Aboriginal burning, Mediterranean climate, Madeira, wild vegetation.

INTRODUCTION

Concern for whether, why, and to what extent aboriginal or prehistoric occupants of the several Mediterranean-climate regions burned the wild vegetation has relevance to this conference in two ways. While naturally caused fires do occur in all continental Mediterranean regions the frequency of burning and thus its intensity based on accumulated fuels would be strongly affected. Secondly the extended time periods of aboriginal burning would allow plant communities time to evolve as adaptations to environments in which fire was regular and frequent.

Omer C. Stewart (1956) has taken perhaps the strongest position on the universality of burning as a human culture trait, going back to the earliest times that man controlled fire and practiced wherever the vegetation was not too wet or too sparse to burn. The vegetation of Mediterranean-climate regions is consistently inflammable at least during parts of the year. Stewart's preoccupation with the subject seems to have arisen from his own field work among the Pomo Indians (1943) who occupied both coastal areas and interior valleys of the Coast Ranges north of San Francisco Bay. His informants' allusions to places they burned annually or less frequently suggested to him that the importance of widespread burning as a cultural technology and a modifier of the society's environment had received inadequate ethnographic attention (1951, 1954).

Examining the documentation Stewart collected[3/] from all parts of the world, from classical literature through travelers' accounts to modern ethnographies, makes it hard to deny his conclusion that deliberate burning of vegetation as well as starting fires accidentally has been characteristic of human societies. Until extremely recent times proscribing such action was unusual.

THE TEMPORAL LIMITS OF ABORIGINAL BURNING

Termination

Although it seems to mix disparate concepts, regarding prehistoric as the equivalent of aboriginal has the distinct advantage of marking a temporal end to the aboriginal period. The introduction of agriculture and domesticated animals does not since the full neolithic with its slash and burn or swidden cultivation practices might only continue or intensify previous burning practices. The beginning of history, however, indicates the adoption of writing and is almost invariably associated with cities, sedentary agriculture, trade, and

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1/ Presented at the Symposium on Environmental Consequences of Fire and Fuel Management in Mediterranean Ecosystems, Palo Alto, Calif., Aug. 1-5, 1977

2/ Professor of Geography, Department of Earth Sciences, University of California, Riverside, California 92521, U.S.A.

3/ Personal communication and unpublished manuscripts by Omer C. Stewart, Department of Anthropology, University of Colorado.

intensive land use for forest exploitation, farming, and pasturage, the attributes of modern society.

Following this definition we find that the aboriginal period for the lands at the eastern end of the Mediterranean Sea ended before 2000 B.C. By 1500 B.C. it was over in Greece and its associated islands. Early in the first millenium B.C. Phoenician and Greek colonists were bringing commerce and cities to Sicily and Southern Italy, Tunisia, Southern France and the southern and eastern coasts of Iberia. In these western lands, however, the transformation was not complete though in Italy it shortly became so. In Iberia and the Maghreb tribes in the interior continued their old patterns of land utilization for many centuries, and not until the full establishment of the Roman Empire at the beginning of the Christian Era could they be considered as other than aboriginal, in parts of Algeria and Morocco not even then. Extending over many centuries rather than a single one the spread of the more advanced culture into the western Mediterranean Basin resembles the entry of Europeans into California, beginning in 1769 and continuing into the 1850's. At points of settlement aboriginal behavior was modified drastically but elsewhere it persisted with only a little change. The final replacement of aboriginal culture patterns, in the Canary Islands, did not occur until the fifteenth century A.D.

The conquest of most of the Mediterranean climate areas of Chile late in the fifteenth century by the Inca Empire brought that region into the realm of Andean Civilization prior to the arrival of the Spaniards in the 1540's (Rowe, 1946). Except in the irrigated valleys of the Norte Chico, however, the native way of life, essentially a neolithic one, does not seem to have been significantly modified by the Inca overlords at the time of the Spanish conquest, about 1545, which can be taken as the end of aboriginal conditions (Keller 1952).

In the Cape District of South Africa, there had been a major cultural change in the native occupation in the century or so prior to European contact. Hottentot pastoralists had almost completely displaced the Bushmen hunters and gatherers from the limited area of Mediterranean climate though the groups were thoroughly mixed in the extensive dry regions of the southwest part of the continent (Schapera 1930). To the extent that aboriginal burning was deliberate there may have been significantly different patterns practiced by the pastoralists for a century or two as opposed to those of the Bushmen which were followed for many earlier millennia. Though reached by the Portuguese in the late fifteenth century effective European contact began with the Dutch provisioning station founded at Table Bay in 1652. Although the Dutch East India Company tried to restrict its territorial outreach the area of mediterranean climate is so small that within a few decades it was fully under European domination (Talbot 1961).

European entry into California found an aboriginal population of hunters and gatherers but one which was remarkably large and had to be extremely adept at exploiting the wild vegetation in its environment. After rapid expansion from San Diego in 1769 to San Francisco in 1776 the mission system stabilized in the near-coastal region where, by plan, it obliterated the aboriginal culture. Well over half of the Mediterranean climate portion of California, however, continued to be occupied by relatively undisturbed Indians until the Gold Rush of the mid-nineteenth century. As a result we have fuller and better records of aboriginal burning practices from California than from any other Mediterranean climate region of the world (Shantz, 1947; Lewis, 1973; Bean and Lawton, 1973). Some data were collected by professional ethnographers who had informants who could remember fully aboriginal practices from their youth (Barrows, 1900; Kroeber, 1925).

Even for Australia the effective entry of Europeans into the two regions of Mediterranean climate on the continent was remarkably late, 1827 in Western Australia and 1837 in South Australia. In those areas the land-hungry European pastoralists were in direct competition with the aborigines and had effectively destroyed them culturally before much interest in the aboriginal ecology and way of life arose. The abundant ethnographic data on Australian Aborigines that we have, in which extensive burning for several purposes figures prominently, come largely from the Center and North, areas with strikingly different climates.

Beginnings

Abbevillian and Acheulian archeological materials found at many places around the Mediterranean Basin demonstrate that man has inhabited the region at least since mid-Pleistocene times. His experience included several glacial advances and retreats in areas farther north with parallel displacements of weather and vegetation belts around the Basin. Protected by its northern mountain rim the area probably experienced only moderate temperature depression, but more southerly storm tracks notably increased precipitation and reduced its

seasonality with expectable effects on vegetation distribution (Butzer 1961). Whether man's ability to enter and occupy the Mediterranean Basin at all depended on his control of fire is less than certain, but there is scarcely any doubt that he controlled it during the last interglacial. Man as a burning agent then has affected the region's vegetation through at least one full glacial cycle of advance and retreat, some hundreds of thousands of years.

The southern tip of Africa may well have had a human population even longer than the Mediterranean Basin. The question of whether he controlled fire for so long a time is more vexed. Non-human hominid populations that probably did not control fire evidently survived into fairly recent times, and except in high areas fire is not needed for survival. Elaborate fire making traditions among the Bushmen, with their generally simple culture, suggest that the culture trait is ancient among them (Schapera 1930).

Recent archeological work in Australia seems to confirm the presence of man in southern parts of the continent 35,000 years ago, full glacial times when because of lowered sea level he could walk from New Guinea. There is little doubt that he was in control of fire from the beginning of this period.

The hotly debated question of whether man's entry into the New World was immediately postglacial, perhaps 12,000 years ago, or much older is relevant but too complex to confront here fairly. My own inclination is to regard the arrival as much earlier, at least 35,000 years ago. Firm radiocarbon dates from a definite archeological site at San Vicente Tagua-Tagua in the mediterranean climate region south of Santiago, Chile make it clear that he had occupied both continents by more than 10,000 years ago (Montané 1968). Further, since passage through Northeast Asia and Alaska would be impossible without control of fire, he is certain to have been able to burn through his entire sojourn in the Americas.

Madeira

There is one area of Mediterranean climate in the world that has no prehistory. The island of Madeira was discovered by Portuguese explorers early in the fifteenth century. Both its name and early descriptions indicate that it was enormously heavily wooded with great evergreen trees similar to but larger than those in the surviving patches of *laurisilva* or *monteverde* of the higher Canary Islands. Shortly after the first settlement in 1420 fires were started to clear lands for planting. They got away and burned uncontrollably, forcing settlers into the ocean for their safety. Some early sources say the fire burned for seven years; others offer a more probable six months, and it is possible that fire clearing of most of the island went on another six years (Ferreira 1959). In any event a permanent change in the vegetation of the island was effected.

In its oceanic position Madeira experiences lightning infrequently and only in connection with winter frontal storms when it is thoroughly soaked. It is likely that, as the chroniclers report millennial trees and an enormous amount of deadwood offered fuel for an almost unheard of conflagration.

The discoverers' accounts seem to indicate clearly that the forests came to the water's edge. Today the lowest 200 meters of the island carry a thorny or succulent vegetation of desertic aspect. Extensive relatively level lands at the crest of the island above 1000 meters are a grassland, grazed almost to a lawn by sheep. Excavations directed toward developing an airport on the high marshy flats of Paúl da Serra exposed charcoaled fragments of tree trunks half a meter in diameter, representing a forest matched nowhere on the island today.

Because lightning-caused fires do occur in most continental Mediterranean climate areas one would not expect to match Madeira's pristine forests in many places were humans not present. But their survival into historic times does suggest that without man vegetative patterns quite different from those we know could exist.

ETHNOGRAPHICALLY RECORDED ABORIGINAL BURNING PATTERNS

Where inflammable materials are present no modern society and probably no aboriginal society that used fire could avoid accidental fires started by campfire embers, torches, or slow matches being carried between campsites. The long dry summers, capped in all mediterranean climate regions except Chile by strong and unusually warm easterly winds, Santa Anas in California, make those regions especially vulnerable. An accidentally escaping fire per camp per year might be a reasonable estimate, not a particularly great incidence compared to the scores of lightning-started fires in a single California mountain range on a day of scattered thundershowers. Lightning, however, occurs only under conditions of high humidity and is generally accompanied by some rain, and

most fires caused by it smoulder out. A camp or cooking fire is most likely to escape under the worst conditions with tinder dry vegetation and strong winds. Because of the palpable danger of a brush or chaparral fire under those conditions one would expect special caution at camps in brushy areas, less in grassy ones.

Accidental fires would then be proportionate in frequency to the population density or the number of villages or camps. Most would not spread significantly but a few would travel over vast areas. My guess, and it could not be other than that, is that in typical areas of Mediterranean climate accidental fires caused by aboriginal man would double the frequency of burning of a given area over what would result from naturally-caused fires.

There are abundant reports of the vegetation being ignited deliberately for a variety of reasons. Perhaps dividing those reasons into immediate effect and deferred effect sets is useful. In the former set fire drives for hunting both large and small animals are the most widely reported. Ethnographic references to 33 tribes of Indians in Central and Northern California using fire to drive game have been uncovered (Lewis 1973), and they may be incomplete. There are similar references in other parts of the world though they are less abundant. A fire drive in dry grass set in late summer or fall would be easiest to start and less risky to the burners than one in chaparral. In areas with adequate precipitation such drives could take place annually; in drier areas a fire might carry only after a wet season. Burning a definable, limited area would be efficient, perhaps a grass opening of at most a few hundred acres that could effectively be harvested annually. A wild fire that burned many square miles would tend to denude a tribe's territory of game for many years.

There is a circumstantial account of the Australian aborigines using fire to aid in attacks on John McDouall Stuart, the first European to enter their part of Central Australia (Webster 1958), and the general uniformity of material culture in Australia would suggest that the technique was known throughout the continent. The use of fire for both attack and defense is known around the Mediterranean Basin from early historic times. Generally speaking such use was a desperation measure, and only occasionally would both the physical and strategic situation be suitable. An incident might be remembered for generations.

Recreational burning is less well documented, and there were undoubtedly tribal taboos against it though I doubt that they were universal. My own experiences with guides in Northern Colombia and Baja California involved backwoodsmen but not aborigines. In Colombia lighting fires in brush country was considered the work of a good citizen. In Baja California the shag of a Washingtonia palm was ignited for fun, and on the windy evening it was only by chance that the whole grove did not burn.

The number of instances in which California Indian informants said that they burned grass or brush to manipulate the environment is remarkable, particularly since most ethnographers were not trying to elicit that sort of information. Lewis (1973) mentions 35 tribes in Central and Northern California who said they burned after harvesting seeds to increase the next year's yield of grass seeds and edible tubers, i.e. in late summer or fall. Planting tobacco on burned-over ground is reported by 22 otherwise non-agricultural tribes. Bean and Lawton (1973) speak of this regular burning of specific valleys and meadows as semi-agriculture supporting their position by noting the unusually large populations maintained by the non-farming California Indians. The Australians for whom tubers played an important dietary role could well have had a like practice since burning normally favors such plants, but there is little ethnographic documentation.

In two ways burning may increase the future hunting potential of a locality. Maintaining edge features between grassland and brush or woodland produces maximally favored habitats for game. This moderately sophisticated wildlife manager's concept is not often reported. Perhaps the aborigines did not have it or the ethnographers did not recognize it when told about it. Resprouting can occur in brush and bunch grasses even before the beginning of the rainy season, and the tender shoots are attractive forage especially late in the dry season when other leaves are dry and hard.

Finally there are reports of burning brush in forests and woodland, particularly in Northern California, to make passage easier and to increase the visibility of game for hunting purposes.

In deliberate burning for environmental manipulation the frequency could easily rise to an annual level. Not enough fuel would be accumulated to produce a wild conflagration except under dry windy conditions and there are indications that the California Indians avoided setting fires at those times. Thus a grassland would burn to the woodland edge but not beyond, or a floor fire would run through a forest without crowning.

Burning grass to obtain better pasture for their livestock is widely reported for the Hottentots (Schapera 1930; Talbot 1961). It probably was also done around the Mediterranean Basin from Neolithic times to the era of the Mesta in Medieval and Early Modern Spain. In areas of Mediterranean climate the general timing of such burns would not be much different from that of hunters and gatherers, but the pastoralists would have reason to burn more extensively. Selecting weather conditions conducive to a maximum conflagration would seem profitable and a wildfire that burned brush land or grassland would be beneficial, at least for a few seasons (Klein 1920).

Finally there is the burning for clearing and planting carried on by Neolithic cultivators practicing shifting slash and burn farming. With rapidly rotated fields such a population would have heavy land demands, and their intent was to change completely the vegetation of the lands they used, at least temporarily. Such practices were carried on around the Mediterranean Basin for prehistoric millennia and for some centuries before the Spanish Conquest in Central Chile. Some recognition of differing soil qualities for planting were probably recognized very early so that favored areas would be returned to, but the big difference in localization from other types of deliberate burning was that woodlands and brushlands were favored over grasslands. In fact the abandonment of a field was normally induced by the problem of grassy or herbaceous weeds. It would not be returned to for a second cycle of cultivation until brush had pretty well displaced the grass. Only in the limited irrigable lowlands would weeding be practiced and the land kept in permanent cultivation.

The cultivators around the Mediterranean Basin also had livestock, and a conflict of interest developed between the pastoralists who would regularly burn the hillsides to maintain a grass cover, and the cultivators who could see abandoned fields returning to brush as potential reserve farmland. In Libya, Morocco, Sicily and Spain the pastoralists, for complex economic, social, and even military reasons, long tended to win the argument, effectively advancing the steppe against the sown (Marsh 1869; Whyte 1961; Despois 1961). In fact the Mesta in Spain effectively maintained regularly burned open range grazing in what might be considered a rurally overpopulated land until the eighteenth century (Klein 1920).

SPECIAL REGIONAL CONSIDERATIONS

Mediterranean Basin

The ecology and way of life of the hunters and gatherers who lived around the Mediterranean Sea for hundreds of thousands of years from Lower Paleolithic Abbevillean to the postglacial period just before the invention of agriculture and the beginning of the Neolithic is remarkably obscure. Postglacial rises in sea level that covered coastal sites, the heavy erosion and alluviation characteristic of Mediterranean climates and accentuated by the mountainous character of most of the Mediterranean Rim, and the activities of larger more technically competent populations who disturbed the most favored settlement areas for thousands of subsequent years may account for the thin paleolithic record. The search for the origins of agriculture has produced a few cave sites such as Mount Carmel and village sites that have pre-pottery, thus presumably pre-agricultural, horizons at the eastern end of the Mediterranean Sea (Whyte 1961; Naveh and Dan 1973; Naveh 1975). Hunting was important to them, but in the Mesolithic small blades with a siliceous crust on the cutting edge have been found that are interpreted as sickles (Sauer 1969), suggesting an important plant food component in the diet.

Almost contemporary but much farther west is the distinctive Capsian culture, centered in southern Tunisia and interior Algeria. Remarkably large populations lived at or beyond the steppe limits of the Mediterranean climate. In their open sites only animal remains survive, but the importance of land snail shells in the deposits suggest an omnivorous diet reminiscent of the Indians of the drier parts of California (Lubell *et al.* 1976). Except at oases the Capsian heartland today maintains only a rather sparse and notably poor population of pastoralists on a notably degraded vegetation.

The Neolithic must have advanced along both shores of the Mediterranean Sea to reach the Atlantic by 3000 B.C., and shortly even beyond to the Canary Islands. Our detailed knowledge of what was happening to the natural vegetation comes largely from considerably later biblical and Homeric sources. Both describe brushland wildfires in vivid terms. References to deforestation by Plato in historic times and the rising prices and more distant sources of lumber in Roman times (Semple 1931) suggest that an equilibrium had been reached in the Neolithic and Early Bronze Age that retained extensive forests on steep slopes and highlands. Growing

urban and maritime markets for timber as the Classical Age advanced led to forest cutting then burning that left grassy pastures or garrigue brushland on what would have been forest, but this is a historic rather than aboriginal product.

An intriguing problem is presented by the open oak woodlands of southern Iberia and France where swine are today pastured on grass and fattened on acorns in season. Swine are an ancient domesticate in this region, (Sauer 1969) and while today the oak woodlands are kept open by grubbing out the brush, the open woodland association might have been established and maintained by frequent burning in prehistoric times (Parsons 1962). The cork oak native to the area is a striking fire adaptation. Lands south and east of the Mediterranean Sea do not maintain the association because of disinterest in pigs since the rise of Judaism and more significantly Islam.

Chile

Two farming systems were practiced by the Chilean Indians at the time of conquest. In the valleys of the Norte Chico from Aconcagua northward canal irrigation and sedentary farming not unlike that of the Peruvian coastal valleys had considerable antiquity. The extensive rugged interfluves were exploited for both wild animals and plants, and fires were caused by hunting and by accident. Though not especially frequent these man-caused disturbances were relatively significant because lightning-caused fires are especially rare in a region that effectively never has summer thunderstorms. Also, the area is dry and woody vegetation does not recover easily.

The extreme denundation of the region found today, however, is the product of the colonial and modern periods when fuel for mines and towns and regular burning of communally held lands to improve pasture were especially destructive. Woodland and brushland survive only in isolated localities or where some protection was offered on large estates (Bahre, 1974).

From the latitude of Santiago southward, even beyond the Río Bío-Bío, commonly taken as the southern limit of the Mediterranean climate, a fairly numerous Indian population practiced slash and burn farming on small plots, working the soil with a weighted digging stick. On the alluvial fan covered sides of a few valleys in the coast ranges the practice survives, going by the name curbén. Digging stick using cultivators could not plant in a grassland so they sought wooded and brush covered areas for their fields, often girdling the plants before burning a plot to increase inflammability. In the fifty years of Inca domination some irrigation probably was introduced by mitimaes or colonists from Peru in the Central Valley between Santiago and the Maule River, but as it was not needed for farming by the more numerous natives probably was not of importance. Llamas and alpacas also were present but not a significant pastoral tradition.

The original vegetation of the level lands of the Central Valley has been displaced almost completely since the Spanish Conquest by crops, weeds, and ornamentals from the Old World. It is likely to have been a grassland swept by extensive and frequent fires. The most circumstantial evidence is that the mounted Spaniards could maneuver and generally defeat the Indians in combat in that region. South of the Bío-Bío where fire cleared fields were scattered and regrowth forest dominated the Indians defended themselves until late in the nineteenth century. There regrowth forests still dominate all the uncultivated land.

Burning is still prevalent in the broken country of the Coast Ranges, but with fairly humid air and accidental topography individual fires are not extensive or particularly hot. Much woody vegetation survives a burn and probably did in aboriginal times unless it was locally extirpated for planting.

California

An appreciation of the importance and character of aboriginal burning in California may best be gained by observing documented changes in vegetation, some of them photographically documented, in the little more than a century since Indian practices ceased to dominate the landscape. Burning by ranchers to clear brush on rangelands in the central and northern parts of the state, although sometimes legally proscribed, may have modified Indian practices only slightly (Shantz 1947). Burning of slash in connection with logging operations, however, introduced a new factor. The available dry fuel could often step up the intensity of a fire, causing it to kill trees left standing and even crown in untouched forests, degrading a forest to a brushland for a long time, perhaps permanently (Fritz 1932).

Perhaps more significant is the modern program of fire suppression and prevention. In the southern part of the state, because of concern for watershed damage and the danger of rapidly running brush fires, and on National

Forest and Park lands for esthetic and political reasons, burning has been fully proscribed, and considerable investment has been made in fire suppression. While such suppression has not been completely successful and great and damaging fires have occurred during this century their frequency in a given area has been notably reduced (Dodge 1975). A recent examination of fires scars on ponderosa and Jeffrey pines in the San Bernardino mountains showed a fire frequency of once every 10 and 12 years, respectively, prior to 1905 when full fire suppression was instituted and every 22 and 29 years after that date (McBride and Laven 1976).

Even more spectacular is the photographic documentation at Yosemite National Park with photos taken from the same points between 1866 and 1961 (Gibbens and Heady 1964). Only Miwok Indians had occupied the valley until about 1854. In addition to tourists and their facilities being present cattle were grazed on the meadows until 1924. The early photos show much more extensive meadows, open stands of conifers, and very little brush. Later ones show a continuing closing of the forest, partly with brush and deciduous trees, and a constriction of the meadows and other grassy areas. Effective fire suppression is the only reasonable explanation of the change from the aboriginal pattern.

There is some evidence (Dodge 1972; 1975) that the greater brush accumulation below and into the open lower edges of the coniferous forests in Southern California resulting from fire suppression is producing hotter fires that crown in the conifers, and is actually raising the lower timberline by killing the conifers at their lower margin where they have trouble reestablishing themselves. In the Sierras Juarez and San Pedro Martir in Baja California where the burning practices of local ranchers, some of whom are Indians, may resemble the aboriginal ones and fire prevention or suppression was not attempted at all until the last few years the coniferous forests are more open and brush free than in comparable sites in the Peninsular Range north of the border.

South Africa

The level and gently rolling surfaces in the limited Mediterranean climate area of South Africa seem to have been covered with grass and herbs at the time of Dutch settlement in the seventeenth century. It is reasonable to assume that regular, end of dry season burning by the Hottentots had established and maintained this association. Such lands, except for wet meadows used to graze dairy cattle, had largely been brought under cultivation by the mid-eighteenth century, and the precise character of their vegetation in aboriginal times is obscure.

The region is bordered on the east by a steep escarpment cut in elevated but largely horizontal sedimentary rocks with some steep sub-parallel ridges, the reexposed roots of ancient mountains, in between. The high level lands north and east of the escarpment have steppe climates without the Mediterranean winter rain concentration. Today a sclerophyllous brush land with many succulent Euphorbiaceae characterizes the lower or rain shadowed areas of steep slopes, and a dense woodland the higher and wetter parts. In these rougher lands some non-pastoral Bushmen bands survived the Hottentot intrusion. They burned for hunting and had undoubtedly had some fire escapes. The strongly accidented terrain restricted the spread of an individual fire so that the frequency of burning of a given plot may not have differed much from the present situation.

Australia

In both Western Australia and South Australia the lands of Mediterranean climate are characterized by low relief, but it is only in the hilly areas and the dry eastern and northern margins that considerable areas of wild vegetation survive, the level and rolling lands being farmed or kept in improved pastures. Two genera, Eucalyptus and Acacia, and one family, Proteaceae, supply most of the woody vegetation, with some of the many individual species occurring as both trees and bushes (Hall, Johnston, and Chippendale 1970). Many also show the fire adaptations of root or crown sprouting and heat stimulated seed germination. Lightning-caused fires are as common as in California or more so.

Records of the burning practices of the relatively large aboriginal populations are scant, but the Aborigines of the North and Center were, and still are, enthusiastic burners, both to improve vegetable food supply and to attract game to the newly sprouting grasses. Similar practices in the South are probable.

There seems to have been little pure native grassland in the Mediterranean climate parts of the continent. There is none now. Open woodland with a mixed brush and grass understory is characteristic of the hilly regions except for the very wet (1500 millimeters of rainfall) southwest tip of Western Australia where there is a closed eucalyptus

forest. The drier parts of Western Australia carried a brushy assembly three to five meters in height with a few tall eucalyptus rising above it whereas in South Australia a savanna with scattered eucalyptus trees was characteristic. All were adapted to frequent fires, which still occur or are set wherever the land is not cultivated. The tall trees are resistant.

The red tingle tree, Eucalyptus jacksonii of the humid southwest tip of Western Australia merits special mention. Fire damaged trees will experience heart rot but the buttresses continue growing, giving hollow shells 25 feet in diameter. The habit is strikingly like that of the California redwood, a species of utterly different phylogeny but growing in a similar environment.

CONCLUSIONS

In all inhabited areas of Mediterranean climate the aboriginal populations burned the vegetation both accidentally and deliberately for many thousands of years. These areas were also subject to naturally caused fires, severe because of the long summer drought, and the resident species had probably evolved their fire adapted characteristics over much more than human time.

Accidental man-caused burns may have roughly equaled the frequency of naturally-caused fires, but their effects may have been somewhat greater as they were likely to occur under dry, windy weather conditions when their intensity could kill even somewhat fire adapted trees. Uninhabited Madeira with forests on now almost desertic lower slopes may afford negative evidence. Where burning was deliberate for economic purposes it could be of annual frequency in grasslands, serving to establish and maintain them on fairly level or rolling surfaces. Brushland and forest burning was less frequent, perhaps every seven to ten years, but this frequency was enough to moderate the fire intensity and permit the survival of an open forest of mature trees that could only reproduce effectively when, for whatever reason, burning did not occur.

Modern practices of fire prevention and suppression, particularly in Southern California, are reducing the frequency of fires well below that of aboriginal times and possibly below their prehuman level. This permits the buildup of fuel from dead brush and new levels of conflagration intensity that are a permanent threat to marginal forest lands.

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FIRE'S EFFECT ON THE ATMOSPHERE[1]

R. G. Vines[2]

Abstract: The convective behaviour of large wildfires is discussed, and the contribution of bushfire smoke to air pollution is assessed. The effect of smoke upon air quality is probably small, even when the smoke is mixed with urban air. Nevertheless, because visibility in dense smoke is greatly reduced, a simple model has been devised which enables us to predict likely visual ranges downwind of typical large-scale prescribed fires.

Key words: fire, convection, smoke, air quality, visual-range, ozone.

Fires will continue to occur in the world's forests and grasslands - be they prescribed fires or wildfires. Indeed, bushfires have burned over much of the earth's surface for many thousands of years; and smoke from fires will go on entering the atmosphere in future, even as it has done from early times.

Research on the nature and properties of bushfire smoke has been carried out in the U.S. and also in Australia, and past work in both countries has been in substantial agreement. I believe much has been done here recently; however I do not know the results of research in the States after 1973, so I hope you will forgive me if I concentrate upon what has happened in Australia.

But before reporting our latest findings on smoke behaviour, I should like to discuss one other important aspect of "Fire's effect on the atmosphere" - i.e. the effects produced by convection. It is well known that the atmospheric circulation induced by a major wildfire with strong convective activity is often similar to that encountered in a severe thunderstorm. Towering smoke columns are normally observed, extending to heights of 20,000 ft or more, and under these conditions the long-range "spotting" of fire-brands is frequently experienced: pieces of burning bark rise high in the air and are blown downwind (in Australia, sometimes for more than 20 miles), where they are responsible for the ignition of wide areas.

Since the dynamics of large convective fires were not well understood our CSIRO Bushfire Section set out to study them (Taylor et al. 1973), and the effects produced during four experimental fires in Western Australia and the Northern Territory have already been briefly summarised (Vines 1973a &1975). For all these fires, when maximum burning-rates were in excess of 30,000 tons of fuel per hour and the convection columns went to heights of approximately 15,000 ft, large volumes of air were entrained amounting to more than 100 cubic miles in every case. This entrained air contained appreciable quantities of moisture; thus, after it ascended to condensation level, convective activity was greatly enhanced by the release of latent heat in the cumulus cloud above the fire. Indeed, the influence of this additional evolution of heat, in causing the smoke column to rise, was shown to be almost as great as that produced by the burning fuel itself. It was also shown that in any major fire, the extent of convection is dependent upon both the burning rate of fuels on the ground and the stability of the air above.[3]

[1] Presented at the Symposium on Environmental Consequences of Fire & Fuel Management in Mediterranean Ecosytems, Palo Alto, Calif. Aug. 1-5, 1977

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[3] When we are confronted with the awesome spectacle of a major wildfire it is evident that such disasters will only be avoided if fuel quantities in the forests are reduced. This is, of course, the basis of the argument for prescribed-burning, or deliberate "let-burn" policies during periods when fires will not get out of hand. For, once fuel quantities are reduced, the intensity of any subsequent wildfire is greatly diminished.

In addition to being able to predict, approximately, the height to which the convection column will rise above a fire, we should also like to know whether smoke in the plume can contribute significantly towards air pollution, and so appreciably reduce air quality[4/]. In early studies on bushfire smoke in Western Australia (Vines et al. 1971), no dangerous concentrations of toxic gases were ever detected in the smoke plumes. Full details of these results were reported at the 1973 Fort Collins Symposium (Vines 1976). In particular, the mean concentration of ozone in the bulk of any smoke column was found to be essentially the same as that for clean air (0.02-0.03 ppm). However, in more recent work in Western Australia, use of an ozone analyser of fast response has indicated that, at the top of the plume, the concentration of ozone can rise above the ambient level, depending upon the length of time the smoke is exposed to sunlight (Evans et al. 1974). It follows that photochemical reactions result during prolonged exposure and, in fact, ozone concentrations of up to $\sim$ 0.1 ppm have been occasionally detected in experiments well downwind of the fire area. These local concentrations at the top of the plume were, therefore, slightly in excess of the U.S. Air Quality Standard of 0.08 ppm. Nevertheless, it can be demonstrated that, by the time this ozone-rich layer ultimately reaches the ground there is ample dilution to, at most, 0.055 ppm (Evans et al. 1977). Consequently, if we are concerned only with conditions at ground level, the earlier conclusion regarding the absence of dangerous concentrations of air-pollutants in the smoke is still valid.

The depth of the layer at the top of the plume where ozone concentrations are enhanced is limited by the ability of ultraviolet radiation to penetrate the smoke. This was shown by ultraviolet measurements within the smoke columns (Evans et al, 1976). Aircraft traverses, at levels nearly 2,000 ft below the top of one plume, indicated that the total ultraviolet flux was reduced to little more than 5% of its value in clear sky. Thus, there is no doubt that the increase in ozone concentration, (which is observed only in the top few hundred feet of a thick smoke plume, and only when the sun is shining), is of photochemical origin; but, as I have said, ozone generation is inhibited at lower levels because of the opacity of the plume.

Despite these findings that air-borne smoke, in itself, is unlikely to be harmful, one important question relates to possible effects arising when rural smokes are mixed with urban air containing industrial pollutants such as the nitrogen oxides (CSIRO 1976). To throw light on this problem Evans made a series of tests in Western Australia, taking grab samples from a smoke plume and adding extra extra nitrogen dioxide to the samples: he then found that the concentration of ozone in the smoke could be further increased above the ambient by up to 50% (Evans et al. 1977). At the same time Evans also found that any photochemical reactions were virtually complete within one hour, for by then the reactants were consumed. This suggests that, if *fresh* smoke is mixed with urban emissions of nitrogen dioxide, ozone generation will increase: but *old* smoke which has drifted in sunlight for an hour, or more, will produce no more ozone - even if mixed with additional supplies of nitrogen oxides from, say, automobile exhausts.

Thus, bushfire smoke which enters a city complex from remote rural areas will be largely non-reactive, and any additions it makes to air pollution and photochemical smog will be determined mainly by the levels of ozone (or other irritants) which it already contains. Hence, the risk that smoke from forest fires will contribute to photochemical smog in city areas seems rather small - at least under the conditions prevailing in Western Australia.

We come now to the effect of smoke itself upon the atmosphere. Since bushfire smoke contains no dangerous concentrations of air contaminants, it does not appear to represent a pollution hazard in rural areas. Nevertheless, smoke is sometimes so dense (Eccleston et al. 1974) that visibility can be seriously impaired, both in the air and at ground level. Thus, if prescribed-burning is to be used on a large scale in our forests as a fire protection measure, it is imperative that we are able to predict where the smoke from prescribed fires will spread.

[4/] Bushfires are obviously a source of atmospheric CO_2: however, Robinson & Robbins (1968) suggest that the CO_2 produced by fires throughout the world is much less than that resulting from other sources. Nevertheless, if we include the global use of wood for fuel, and effects produced by deforestation and the decomposition of peat and humus etc., the annual contribution of CO_2 to the atmosphere is certainly of the same order as that arising from the burning of fossil fuels. It is well known that the CO_2 content of the atmosphere is increasing rapidly and that, if the trend continues, climatic changes could result: for a recent discussion of this question, see Pearman (1977).

With this in mind, the nature and composition of smoke particulates has been investigated, and their size-distribution and concentrations under given conditions have been determined (see, for example, Vines et al.1971). Our recent research has demonstrated that there is little agglomeration of the particles in thick smokes while they are blown downwind (Packham & Vines 1977). In particular, we have measured the flux of particles through a vertical plane in the smoke plume close to a large prescribed fire in Western Australia and, by repeating these measurements for the same smoke-sample many miles downwind, we were able to show that the particle count remained unaltered. The total *mass* of smoke in the sample was also unchanged.

It follows from these observations that there was little ageing of the particles, as the smoke was blown away. Using this information, we have constructed a simple model (cf Packham & Vines 1976) from which it is possible to predict the minimum visibility likely to be experienced at ground level, downwind of any large prescribed burn in a forest area.[5/]

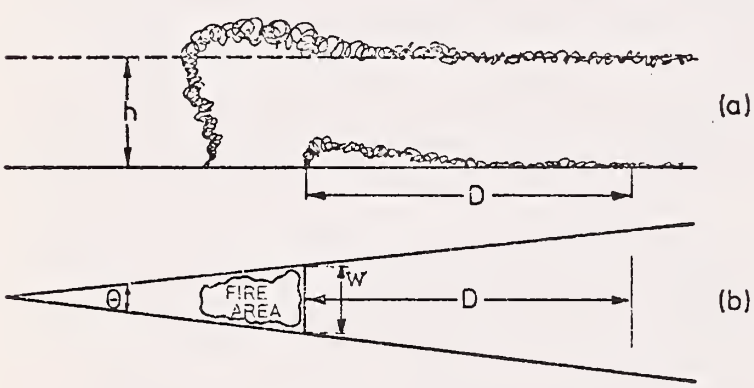

Figure 1

5/ It is worth noting that the scattering per particle b_s/N — where b_s is the scattering coefficient (m^{-1}), and N the number of particles (m^{-3}) — does not vary greatly from fire to fire, nor with particle concentrations in the smoke. The value of b_s/N for typical smokes from prescribed fires in Western Australia is $\sim 2.10^{-14}$, which is not greatly different from that for continental hazes in the U.S.A. (Willeke & Whitby 1975).

In figs. 1a and b, a schematic representation (in elevation and plan) is given of the smoke plume from such a fire. Here "h" (metres) is the height of the atmospheric inversion beneath which the smoke is trapped, and θ is the included angle of the plume as the smoke moves downwind — which, for all practical purposes, is between 12 and 13° with moderate winds of between, say, 10 and 30 knots (Vines et al. 1971). Previous work has also shown that the mass of smoke evolved from large-scale prescribed burns in Western Australia is roughly 3% of the total mass of the forest litter consumed (Evans et al. 1976). Thus, if certain other parameters are known, the visual range in the smoke at any point downwind of the fire area may be derived[6/].

In this way we can calculate (Packham & Vines 1977) that the *minimum* visual range (in metres), on the ground at a distance D (metres) downwind, is approximately equal to:-

$$2.4 \frac{h\ v\ t}{M\ A} (D + 4.5\ w),$$

where

M is the fuel concentration (g/m^2)
A is the fire area (m^2), and w its width (m)
t is the burn-out time (h), and
v is the wind velocity (m/h).

This result relates, of course, to the most concentrated parcel of smoke evolved at the height of the fire, as experienced on the ground at distance D downwind while the smoke is being blown away.

It is clear that the model described above has considerable application in the planning of large-scale burns by Forest Authorities. For if foresters could predict the minimum visibility likely to be experienced in country areas as a result of prescribed fires, this would be of benefit in making operational decisions : furthermore, by minimizing smoke nuisance, the authorities concerned could ensure that the general public are inconvenienced as little as possible.

One further question remains, related to the problem of where smoke finally goes. Past work has indicated that the majority of the particles are much too small to settle (being approximately 0.1 μm in diameter): thus, apart from evaporation of the more volatile tars, and oxidation, (both of which appear insignificant over times of the order of hours, but may become appreciable over days and weeks), the ultimate means of

6/ Topographic effects have been ignored in formulating the model.

removing smoke from the atmosphere would seem to be the scavenging action of rain. But, in the absence of rain, smoke particles can probably persist in the atmosphere for very long periods.

At the Tall Timbers Conference in 1973, I concluded my talk on "Bushfire smoke and air quality" with a speculative suggestion (Vines 1973b) which I should like to repeat here. Many of the particles in natural smokes consist of finely divided carbon which is highly absorptive (see Komarek et al. 1973). Such carbonaceous components of smoke may have served, in times past, to cleanse the air of undesirable compounds (cf. Komarek 1973) and keep it free of toxic gases (e.g., the sulphurous fumes arising from volcanoes). Indeed, bushfire smoke may *still* be beneficial to us all by helping to remove present day industrial pollutants from the air; and should we, by means of modern technology, ever succeed in preventing the occurrence of rural fires, we might well do ourselves a disservice!

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FIRE EXCLUSION PRACTICE--COST AND BENEFITS[1]

John A. Zivnuska[2]

Abstract: Total fire exclusion is not and never has been a valid option in Mediterranean ecosystems. The issue is that of costs and benefits associated with alternatives. Both the cost and benefits associated with management changes in the role of fire depend on a particular ecosystem and the successional stage. The outcome is not deterministic. Changes in management practices result in changes both in possible outcomes and their probabilities.
Key Words: fire exclusion, fire control, prescribed burning, cost/benefits ratio, successional stage.

Now it can be argued that the economics of fire exclusion and the economics of prescribed burning are simply two sides of the same coin. If a management policy of fire exclusion is to be evaluated, the evaluation must not only attempt to weigh the costs and benefits of the policy against each other but must also weigh these results against those to be expected under a management policy of fire inclusion. The reverse statement also holds. Under this interpretation, it really makes little difference whether one begins with fire exclusion or with fire inclusion, because both must be evaluated before the job is done.

In general terms, I agree with the argument that the evaluation of a policy requires the evaluation of alternatives. However, in this instance I would like to raise the question as to whether or not we have a coin here at all. Quite frankly, I question that fire exclusion has ever been practiced effectively or even attempted in a full sense of the term in Mediterranean-climate ecosystems.

When I began my studies of forestry in California more than 40 years ago, Show and Kotok (1924) had presumably shown that the effects of "light burning" were adverse on balance. The use of any form of broadcast burning for type conversion was illegal and the emphasis was on a strong system of fire control. The period is often mentioned as an example of a fire exclusion policy. In fact, however, at that very time Federal foresters were requiring the piling and burning of slash on timber sales as a fire hazard reduction practice. Rather than a fire exclusion goal in fire control, official policy was based on an "allowable burn" objective (U.S. Department of Agriculture, Forest Service 1933) which involved defining for each forest type "the percentage of the area that may burn over annually without impairing radically the forest values as determined by the predominant purposes of management." The issue then as always was that of the form and extent to which fire should be a factor in the management of the ecosystem.

While I think it important that this be recognized, I do not mean to deny the great differences which exist between an essentially defensive management policy of sharply limiting the extent and form of fire's role in an ecosystem and a positive policy of deliberately using fire as a management input through various combinations of "let burn" and "prescribed burning" practices. My point is that the management decision to be made is not that of a choice between opposites but rather that of determining where to operate in a broad but continuous spectrum of possibilities.

To return to the title of this paper, the question seems to be that of the costs and benefits of a management policy of sharply limiting the role of fire in various ecosystems. In attempting to analyze the results of the effective implementation of such a policy, it is useful to consider separately two interrelated patterns -- the effects on the successional development of the vegetation and the effects on fuel loading and fire hazard.

Broadly speaking, as the role of fire in an ecosystem is increasingly restricted, we would expect a gradual development over time of a more complex vegetative structure, characterized by a greater variety and mixture of age classes, greater diversity in species

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[1] Presented at the Symposium on Environmental Consequences of Fire and Fuel Management in Mediterranean Ecosystems, Palo Alto, Calif., August 1-5, 1977.
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complete lack of any efforts directed at fuel management within the somewhat limited programs of land management which were then being developed.

Now, consider any type of ecosystem which is currently under a management regime which does not include the prescribed use of fire. Fuel management may or may not be a part of this management regime, either directly through chemical or mechanical control of fuels or indirectly through the design of vegetative patterns, the choice of species, the spacing of trees, or similar practices. Future development of the vegetation may follow any one of a number of widely varying patterns of development in the future. The vegetation may develop in the complete absence of fire, under the influence of frequent light fires, or under the impact of a major conflagration. Each such possible sequence has its own set of probabilities. The effects of any fires which do occur will depend not only on the exact conditions under which they burn and their intensity and size, but also on the weather patterns which follow them. Again, we are dealing with probabilistic phenomena.

Thus, in attempting to manage such ecosystems we are not working with deterministic systems but instead with systems marked by major uncertainties, with possible outcomes predictable in probabilistic terms at best. To the extent that our knowledge is adequate, we should be able to describe the changed set of possible outcomes and estimate the probability that each such outcome will actually be realized. I must add that rarely if ever is our knowledge this adequate.

The argument here can be generalized. Through changes in our management practices, we can modify the role of fire in the ecosystem being managed. This is true whether we move in the direction of fire exclusion, with an intensification of direct control measures and greater restrictions on the use of fire or in the direction of active fire management, with increased use of prescribed burning and let burn practices. Regardless of the direction of shift, we replace one set of widely varying possible outcomes, each with its own probability, by another set of possible outcomes with their own probabilities.

It is only when we can estimate the possible outcomes of such a series of management alternatives in probabilistic terms that we are in a sound position to proceed with an evaluation of costs and benefits. In vegetation management, the biologist must provide the economist with basic production function information in meaningful terms. The economic analysis can be no stronger than the biological expressions on which it rests, and is likely to be weaker since it adds the inadequacies of economic knowledge to the inadequacies of biological knowledge.

If we can predict the possible outcomes of alternative management regimes with some degree of confidence, we can then specify the alternate production systems in terms of physical inputs, physical outputs, and the probability of their occurrence. In an economic sense, all of the inputs represent costs. The outputs, on the other hand, may be either cost or benefits, depending both on their nature and on man's wants and desires. In either case, such outputs should be appropriately weighted by the probability of their occurrence.

The direct costs of inputs such as planning time, manpower requirements, equipment costs, and materials can usually be estimated without any special problems. Operationally, the main difficulty is with incomplete specification of inputs. This seems to be particularly true in the case of estimates of the costs of prescribed burning.

Somewhat greater difficulty is likely with overhead costs, although again the problem is largely one of incomplete specification of inputs. An example here would be a practice requiring the assembling of appreciable manpower and equipment but subject to sudden changes in scheduling because of meteorological conditions. While in a small, flexible operation such shifts can be accommodated at little cost, with large scale application of similar practices by a bureaucratic organization such costs can become substantial.

The major difficulties, however, are those associated with the outputs. First, there is the uncertain or probabilistic nature of such outputs and the fact that the outputs may be widely separated in time from the inputs. For example, a particular management practice, be it fire exclusion or prescribed burning, has some probability of resulting in the development of even-aged stands of trees. A part of this output may be increased susceptibility of the forest to crown fires or to snow breakage, but the incidence of such problems is likely to be substantially removed in time from the initial input leading to them.

Second, there is the need to determine if an output is a cost or a benefit. Among other considerations, this will depend on man. For example, assume that a particular management regime in a forest either results in or requires a light fire which opens up

composition, and a higher ratio of tolerant to intolerant species than was found in the earlier period. This would be in marked contrast to the initial development following a fire or other major disturbance under a regime of effective fire control, which may well be characterized by a wave of even-aged vegetation.

Whether or not such a change in vegetation constitutes a benefit to man will depend on both the successional stage involved and the nature of man's wants and desires relative to possible outputs from the ecosystem. There is no a priori basis for assuming that either preclimax or climax vegetation is the more desirable, although in the case of timber most of the preferred species are intolerant and characteristic of preclimax conditions.

The effects on fuel loads and fire hazard will, of course, be closely tied to the successional stages involved. With an effective fire control system, the early successional stages following fire or other disturbance are likely to be marked by a rapid build-up of fuel loads and fire hazard, but in more advanced successional stages the relationships will become more complex. In many circumstances there seem likely to be substantial periods which will be marked by appreciable reductions in hazard as a result of changes in the distribution and nature of the total combustible material.

It is sometimes asserted that an initially effective fire control system results in a fuel build-up which rapidly increases the probability of destructive fires. Thus by its development the vegetation tends almost to self-destruct through accumulating susceptibility to fire. Certainly there are examples of this pattern in California as well as elsewhere. However, they seem to be the product of specific ecosystems at particular successional stages and in addition they seem to reflect an absence of other fuel management practices as well as an absence of fire. It has not been demonstrated that this is a necessary general condition.

There are also statistical records for some areas in Southern California which seem to show that increasing the intensity of fire control efforts has little effect on the rate of accumulation of total burned area over time. However, the earlier accumulation of total area burned through frequent small steps has been replaced by less frequent but much larger steps. Commonly, those results of fire which man considers beneficial tend to be inversely related to the size of the individual burned area, while those which man considers adverse are positively correlated with size of the burned area. Thus, if the total area burned over time is not affected but the distribution of fires shifts to an increasing role for large fires, the result can be a significant cost for society.

To illustrate some of these concepts further, I would like to turn again to the historic record in California. Prior to the arrival of European man, many of the ecosysems of the Sierra Nevada appear to have been subject to fairly frequent and extensive burning as the result both of unchecked natural fires from lightning and other causes and of deliberate burning by at least some Indian tribes. Whatever the effects of such earlier burning on vegetation patterns and fuel loadings, they seem clearly not to have been such as to preclude major fires. Following the arrival of the early Spanish settlers with their reliance on a grazing economy there came a rapid acceleration in burning. By the middle of the last century the effects of miners and loggers were added to those of the increasing numbers of cattlemen and sheepmen. This period of accelerated burning continued well into the 20th century. The fuels were there for burning. The vegetation was surely a complex mosaic of conditions. Every historical or literary reference to the tall open forests or to riding horseback through the trees can be matched by another citing the density of the brush or the impenetrable nature of the wilderness.

Some of the most vivid descriptions in the English language of major crown fires in high forest stands are to be found in the writings of John Muir, based on his extensive travels in the southern Sierra Nevada during the final decades of the pre-fire control period. Indeed, it was Muir who wrote in 1878 that "fire, whether occurring naturally by lightning or through the agency of man, is the great master-scourge of forests, and especially of sequoia."

As the new policy of fire control became increasingly intensive and effective following World War I, the results which occurred were the product of this earlier history of fire as well as of the new policy of strict fire control. The stage has been set biologically for the new policy to produce a particular pattern of results. Further, the results were influenced in appreciable degree by the effects of grazing, logging, and all the other intrusions of man into these ecosystems. And the results were also affected by a nearly

the crown canopy to some degree and also disturbs conditions on the forest floor. The result may be the establishment of an appreciable understory of brush. If the species involved are palatable, such an output may be a benefit for the game manager whose purpose is to increase carrying capacity for deer. However, the same result would represent loss of site control and an appreciable cost for the silviculturist intent on growing trees for harvesting. Obviously, many environmental effects will be more subtle and difficult to evaluate than this example.

Third, particular difficulties are associated with the unintended outputs or side-effects of programs. For example, a program of intensive fire control designed to limit sharply the role of fire in an ecosystem presumably is expected to produce outputs such as a reduction in damage from fire and the development of particular kinds of vegetative patterns. However, it may also result in increased fuel loads, increased fire hazard, and some increase in the intensity of fires which do occur. Such outputs should be appraised and recognized as costs of the program.

Similarly, prescribed burning programs presumably are carried out where it is believed that the benefits on the area to be burned will be greater than the costs of the program. However, one of the outputs of any prescribed burning program is escapes and the burning of areas not included in the plans. Every program of prescribed burning of which I know, whether the purpose be type conversion, hazard reduction, right-of-way clearing, or the clearing of reservoir sites, has a record of escapes ranging from minor slopovers to major conflagrations. The results may range from unexpected additional benefits to major losses amounting to millions of dollars.

Thus, one cost of prescribed burning is the risk of damage from escapes. The cost of this risk could be measured by the aggregate of the costs associated with each of the possible escape outcomes appropriately weighted by its probability of occurrence. Even a very low probability of a very high cost can be a significant cost element affecting decisions. In fact, it is just this cost which seems to be a major factor in limiting the use of prescribed burning in many situations, yet I have never seen it estimated and included in the cost of prescribed burning programs which are proposed.

As a fourth and final point on outputs, I would like to mention the problem of determining the change in magnitude and nature of outputs resulting from a change in management practices. For example, a program of prescribed burning may be introduced to yield benefits including the reduction of erosion, air pollution, timber damage, and loss of regeneration resulting from wildfires by reducing the incidence and intensity of such wildfires. However, the prescribed burning itself will also yield outputs including effects on soil erosion, contributions to air pollution, scarring and even killing of mature trees, and destruction of regeneration. The problem is that of determining the net changes achieved. Now in most cases it can probably be demonstrated that the per acre adverse effects of a controlled fire will be very much less than those of those of an uncontrolled wildfire. However, this is not really the problem at issue. What we need to know and generally do not know is the cumulative contributions of an area-wide rotational prescribed burning process carried out over a region or district as compared to the probable reductions in adverse effects of wildfires in that region or district over the same extended time period. Here is an area of research in the role of fire in the environment in great need of study and in which the literature of the field is sadly lacking.

One other aspect in the evaluation of costs and benefits remains to be covered. This is the role of human institutions -- our laws and regulations and the way in which our societies are organized and function. Here I will limit my discussion to two examples.

For our purposes, a particularly important group of institutions are those related to land ownership and use. Generally in the United States, and probably in other countries as well, we are moving to an increasingly complex and fragmented pattern in both the ownership and the use of land. This can result in rapid and major changes in the costs and benefits associated with management practices. One of the fundamental concepts in the property rights of a landowner is that he must not use his property to the injury of others. Fragmentation of ownership increases the probability that action on one property may adversely affect another property. Furthermore, contrasting land uses such as human settlement interspersed in wildland areas or forest plantations adjacent to rangelands magnify the values at state in such possible adverse effects. The effects of this on practices such as prescribed burning or the use of chemicals in vegetation control are obvious.

In California, these institutional developments have reached a stage such that some people believe that effective land management is threatened. Proposals have been made that the state relieve private owners of the responsibility for losses due to escapes of prescribed fires under certain conditions. If such a proposal is for a state-sponsored program of insurance against liability from escaped fires, the costs of which would be carried in full by the premiums paid, then the effect would simply be to redistribute the risk so that a certain but bearable cost would replace an uncertain but potentially unbearable cost. The only questions here would be as to the level of the rates and the volume of business. If, however, the intent is that the state would assume the costs directly rather than redistribute them among owners, then the situation is quite different. This would mean that owners would then make their fire management decisions without consideration of true and appreciable costs to society. The direction of effect here would be toward decisions contrary to the interests of society. Such a proposal would run exactly opposite to the whole thrust of the environmental movement of the last decade, which has been directed to ensuring that costs to society as well as to the individual enterprise are recognized in decisions affecting the environment.

My other example of institutional factors involves laws and regulations directed to control of air pollution. Technical aspects involving the relationship between fire and air pollution are covered elsewhere in this symposium and are not my concern here. My comments are directed only to the provisions regarding nondeterioration which have developed under the Clean Air Act with reference to areas such as National Parks, Wilderness areas, and surrounding lands. Strict interpretation and enforcement of these provisions as a result either of regulations or court decisions could act to preclude activities resulting in the emission of smoke into the atmosphere in such areas. In effect, such an institutional development would increase sharply the costs of management programs involving the use of fire and thus would act to shift management away from the use of fire and in the direction of fire exclusion. At the moment our institutions in this area can only be described as uncertain and subject to possible sudden change.

In conclusion, I would like to summarize my main points. First, total fire exclusion is not and never has been a valid option in Mediterranean-climate ecosystems. The issue is that of the costs and benefits associated with alternatives as to the form and extent to which fire is a factor in the management of such ecosystems. Second, both the costs and the benefits associated with a management-induced change in the role of fire in such an ecosystem will depend not only on the particular ecosystem involved but also on its successional stage, tending to change over time with the development of the vegetation. Third, in any ecosystem under a particular management regime the outcome is not deterministic. Instead, there is a whole set of possible outcomes, each subject to some probability distribution. Fourth, changes in management practices result in changes both in the set of possible outcomes and in their probabilities. Fifth, if ecosystem processes under management can be described in these terms, they can be defined as production systems with specified inputs and outputs. Sixth, the inputs are costs and can usually be estimated without major problems. The main difficulty here is in incomplete specification of inputs. Seventh, the outputs may be either costs or benefits, depending on their nature and on human purposes. Substantial difficulties, both practical and conceptual, are encountered in the evaluation of outputs. Finally, in any such evaluation close attention must be given to the institutional environment. Changes in our institutions can result in marked and rapid shifts in costs and benefits.

In total, such an approach to the evaluation of costs and benefits of management practices related to fire is complex, but so is the role of fire in the environment.

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PRESCRIBED FIRE AS A MANAGEMENT TOOL[1]

Harold H. Biswell[2]

Abstract: I like the idea of prescribed fire as a management tool. This involves setting fires in selected places under conditions of weather and fuel moisture that enable one to manage the spread of flames and intensity of heat desired to accomplish certain planned benefits. It is working in harmony with, and not against nature.

Prescribed fires should be widely used in California forests, chaparral and brushlands for a variety of benefits. The most important benefit would be a reduction of fuels, making wildfires less damaging to the environment and more easily controlled. Burning should be done by trained and experienced personnel only. Our most important need is to select and train people for this work. Prescribed fire is poorly understood, resulting in confusion and resistance to its use.

Key words: Prescribed fire, fire ecology, fire management.

INTRODUCTION

For 36 years I have studied and used low intensity fires in forests and brushlands, 30 of these in California. Six years were spent in the coastal plain of Georgia. In 1961-62 I spent 4 months in the Mediterranean areas of Italy, France, and Spain looking at fire's role in the vegetation.

Prescribed fire as a management tool is an interesting and challenging subject for three reasons: first, it is working in harmony with, and not against nature. Now, what could be more interesting than unravelling nature's secrets? Second, fire is a powerful tool--used wisely it can be very rewarding, but in untrained hands, it can be devastating. Third, fire is related to almost every aspect of the environment--the soils and water, the atmosphere, plants and animals, diseases and insects, people and politics. There is no end to what one can learn. Always there is something new to arouse ones imagination, curiosity, and enthusiasm.

Prescribed fire is both a science and art. The science is largely concerned with the environmental consequences of using fire and the conditions under which fires are set. The art is concerned with managing the rate of spread and heat of fire to obtain certain planned benefits. One is as important as the other.

Some people worry about the environmental consequences of prescribed fire use. They want to learn more about the effects of fire before any deliberate burning is done. On the other hand, I am more worried about what happens with virtual fire exclusion, for this is something new and unnatural in forest and brushland environments. Prescribed burning is simulating the low intensity natural fires that have burned over the landscape for centuries.

SOME PERSONAL EXPERIENCES IN USING FIRE AS A MANAGEMENT TOOL

In Georgia

My first interest in prescribed fire as a management tool was gained in the coastal plain of Georgia in 1940. I was in charge of range research at the USFS forestry Expt. Sta.

[1] Presented at the symposium on Environmental Consequences of Fire and Fuel Mamagement in Mediterranean Ecosystems, Palo Alto, Calif. Aug 1-5, 1977.

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Ashville, N.C. Following surveys, we decided to study the use of fire as a management tool in integrated resources management in longleaf and slash pine forests, particularly the coordination of timber production and livestock grazing.

Objectives of burning in longleaf and slashpine forests had been to reduce debris and logging slash, control brush in the understory of trees, prepare seedbeds for forest tree reproduction, control brown spot disease on longleaf pine, and improve conditions for livestock grazing and game, including both deer and quail. In our particular studies, timber production was assigned primary use with grazing secondary. Frequency and intensity of fire was regulated to obtain reproduction trees in optimum amounts.

During the early forties very little prescribed burning was done in the southeastern pine forests. Much confusion and controversy existed because the effects of fire and the expertise of burning were little understood. Also, at that time the bad results of virtual fire exclusion had not yet come to light. Thus, there was great resistance to the use of fire. This was discussed by Ashley Schiff (1962) in his book "Fire and Water, scientific heresy in the Forest Service."

In 1941-43 large wildfires in the piney woods of Georgia convinced some foresters that virtual fire exclusion is not the proper and final answer in good forest management. Thereafter, the use of prescribed fires gradually increased so now about 2,500,000 acres are burned annually. Foresters there consider prescribed fire as one of their principal tools in forest management.

Early in the planning stage of our studies in Georgia, a forester invited me to accompany him on a trip to the 80,000 acres of Brunswick Peninsula Co. lands, now Union Camp, to inspect the prescribed burning they had been doing. This was an eye-opening experience. One elderly person had been assigned the job of burning. It was his sole responsibility and he worked alone, making full use of roads, past burns, and his experiences with the flammability of fuels. He managed with full control of the flames. He had patience and burning was easy because he had much experience and knew exactly how to go about it. His knowledge was gained from experience, not from books nor in scientific meetings. This was an important lesson to me. <u>In prescribed burning, experience is a valuable teacher</u>.

After our studies were planned and burning about ready to be started, the Director of our Forestry Expt. Sta. at Ashville visited in Tifton, Ga., near the experimental range. At the dinner table that evening he said: "When are you going to start the burning? I would like to see some of it." I thought a moment and suggested that we might burn a small area that night. In the cool of evening, about 8:00 p.m., we lit a fire near the road beside a swamp where the fire could be easily controlled. But there was no breeze and the flames from burning tall wiregrass and pine needles went straight up and severely scorched pine needles on trees 12 to 15 ft. tall. This was another important lesson -- <u>never prescribe burn on level ground without a breeze to keep the flames down and to dissipate heat</u>.

The Director of the Forestry Expt. Sta. was supremely interested and gave full support. It is interesting, however, that during the 6 years I researched in Georgia that not a single manuscript came from my pen. I knew very well that the Washington office would resist so I refrained from publishing. A young forester is always interested in pleasing those above him for he wants promotions at a somewhat normal rate. At least, he does not want to be fired or transferred.

In California

After accepting a position in range management at U.C. Berkeley, I went by the Washington D.C. office to express my regards. The Chief of Research said: "Now when you go to California stay away from studies of controlled burning Work on grazing in the mountains or somewhere else, but in any case, stay away from fire." I thought this good advice because I had heard about the controversy in California.

Very soon after I arrived in California, Chief of the Big Game Div. of the Calif. Dept.of Fish and Game, asked if I would be interested in studies of game range improvement through controlled burning. He insisted that the studies were important and necessary and that the Dept. of Fish and Game could transfer money to the University for this purpose, perhaps in the amount of $25,000 per year. As to the Washington advice, I had concluded that if controversy exists it only means that more research and clarification is needed. I then talked to the chairman of the U.C. Dept. of Forestry and together he and I talked to the Dean of the College of Agriculture. The Dean thought these studies highly worthwhile and suggested that we go ahead and accept the offer, The chairman of the Dept. of Forestry gave good advice. He suggested that sound research projects be set up, and that we listen to others if they

have suggestions, but not argue about results, and let the chips fall where they will. This was excellent advice and has been followed ever since. Our studies in California started in 1947 and are still underway.

Financial support from the Calif. Dept. of Fish and Game lasted for 12 years, using Pittman-Robinson money obtained from taxes on arms and ammunition. Six years of study were devoted to prescribed burning in chaparral in Lake County and 12 to woodland-grass chaparral in the Sierra foothills of Madera County. Burning in ponderosa pine was done for 10 years at both Hobergs in Lake County and the Teaford Forest near North Fork in Madera County. Several of these studies continued to 1964 without further financial support from the Dept. of Fish and Game. In 1965 studies were started at Whitaker'Forest on Redwood Mountain next to King's Canyon National Park. This continued from the spring of 1965 through the spring of 1974 under a contract arrangement between the University of California and the Calif. Dept. of Forestry. In the meantime, limited burning was done in eucalyptus and Monterey pine in the hill areas of the Univ. campus. In the fall of 1975 a prescribed burning program was started in the south grove area of the Calaveras Big Trees State Park, where I serve as consultant. The burning there is more of an action program than research. From all of these studies and the longer I work with fire, the more convinced I become that it can be an excellent management tool.

Initiation of research in chaparral and woodland-grass chaparral was easy because the state legislature had authorized the Calif. Dept. of Forestry in 1945 to issue control burning permits to ranchers for brush range improvement. By 1947 a few ranchers had already started burning The state Forester was quite enthusiastic. Furthermore, the U.C. College of Agriculture had a rangeland utilization committee whose members were interested and active. Everything seemed perfect. But when the thought of prescribed burning in the understory of ponderosa pine was mentioned, foresters were much alarmed.

Every summer severe wildfires were burning in California's vegetation causing much damage (fig. 1). Expenses in fire control were awful. Certainly something seemed to be wrong with management in letting fuels build up to create such holocausts. Many times I mentioned the possibility of using prescribed fires to reduce fuels, but on each occasion I was reminded that in California it is either too wet or too dry to burn; furthermore, it cannot be done on steep slopes. They spoke as though those slopes had never before been burned by low intensity fires.

Figure 1--Heavy soil erosion following severe wildfire.

Finally a forester friend suggested that I demonstrate prescribed burning in the understory of trees. Obviously, this was a good idea and a challenge, and I proceeded to obtain permission to do research on the University's Blodgett Forest. Every approach was tried but none proved successful. I knew there would be no reward in going to the Forest Service nor the Calif. Dept. of Forestry; so the only alternative was to contact private citizens who might be interested in reducing fuels and fire hazards on their own properties. Otis Teaford, a rancher-forester in Madera County, and George and Frank Hoberg, resort owners in Lake County, were approached and found anxious to cooperate. On both properties ponderosa pine was the principal tree. Fire hazards were extremely severe. Thus, my studies on prescribed burning in forestry were started on the Teaford Forest in the spring of 1951 and at Hobergs in the fall of 1951. In both places the main objective would be to reduce fuels and create conditions where the wildfire danger would not be so great.

In the spring of 1952 a field day was held at Hobergs to observe results and hold a demonstration burn. The following experience will further serve to illustrate opposition in California to the use of fires in the understory of trees for fuels reduction. Less than a week after the field day demonstration I received a letter from the Dean of the school of forestry expressing his opposition to the research, and suggesting that it would be wise to withdraw my work from Hobergs' resort. To make his views and action well known, copies of the letter were sent to the state forester; the chairman of the Calif. State Board of Forestry; and the chief of fire research in the Forestry Expt. Sta.. If I had

yielded and the work had stopped at that time, research on prescribed burning in the understory of trees in California might have been held back for many more years.

True, there was much opposition to my first research on prescribed fire use in forests; however, it has gradually decreased year by year. As for the future, I expect to see much more burning in the understory of trees. Eventually prescribed fire will become one of the principal tools in forest land management here in California. Forest management must be planned so that fire can be used effectively. This must be done, for wildfires are causing too much damage and are too costly. I repeat, we must work more in harmony with, and not so much against nature.

CALIFORNIA'S WILDFIRE PROBLEM

The severity of wildfires over California's landscape is well known. The problem of fire was pointed out in part in the background statement of the program. Nearly every year large and destructive wildfires do tremendous damage. For example, in 1955 from August 27 to September 13, 307,222 acres were burned of which 141,222 were timberland (U.S. Forest Service 1955). Again in 1970 from September 22 to October 5 a total of 773 separate fires burned nearly 580,000 acres of grass, brushland and timber throughout the state (Phillips 1971). During this short period the fires destroyed 722 homes, and 16 lives were lost. Suppression and damage were estimated at 233 million dollars. Attempted rehabilitation of the forests and watersheds will cost other millions. The laguna fire in San Diego County, was the second largest ever recorded in California history. To some people this seems strange because we have the best trained and equipped fire fighting forces in the world. But when the fuels are examined the picture becomes clear; too much fuel, too wide spread (Dodge 1972; Philpot 1973; Countryman, 1974). Bad fires can be expected, not necessarily because of hot, dry winds alone, but because of fuel accumulations (fig.2).

Hundreds of towns and villages in Calif. are surrounded by dangerous fuels and most of the people seem little concerned about the fire danger (Biswell 1972, 1976). The "Berkeley fire" of 1923 is something to remember. This town is surrounded by regional parks, public utility lands, wildlands of the Univ. of Calif. and a few other relatively large undeveloped areas in private ownership. On September 17, 1923, a hot, dry northeast wind of 40 mi. per hr. brought a fire over the ridge east of Berkeley. The fire spread quickly through a grove of eucalyptus and suddenly burst out into the residential area below, apparently having reached this area by firebrands from the eucalyptus. Within 40 minutes after the first house caught fire at 2:20 p.m., burning shingles were sailing over the roof tops throughout an area a half mile square. Within another 2 hours with humidity of 25% and temperature of 90°F, 625 houses and buildings were destroyed. Miraculously, no one was burned.

Figure 2--Severe fire hazard where prescribed fire could be used to reduce the fuels and favor forest reproduction.

One wonders what might have happened on September 17, 1965, if fires had developed when hot, dry winds blew all day and all night at 60 miles per hour. Unless something is done about the fuels another holocaust will occur--we don't know when--because the fuels around Berkeley are even greater now than they were in 1923. The worst fuel is eucalyptus with its draping, oily bark that can send firebrands far ahead of the flames in a strong, hot,dry wind. Many people could be burned. Wouldn't it be wise to prescribe burn under the eucalyptus and also Monterey pine in the coolness and dampness of early spring when the grasses are still green? In this way, the fuels could be reduced and managed to make Berkeley a safer place to live. Only resistance to the use of fire by professionals keeps this from being done.

The expenses of maintaining fire control organizations and controlling wildfires are tremendous. No one knows exactly how much, but the amount is astronomical. In the future, more effort should be put into fuels management so costs related to wildfires can be reduced. This can be done through much greater use of prescribed fire as a management tool.

OBJECTIVES AND BENEFITS OF PRESCRIBED BURNING

Prescribed fires may be used for many purposes in different types of vegetation. The following discussions will point out the objectives and some of the results with our burning in forests, chaparral, and woodland-grass chaparral areas. It happens that a prescribed fire set for one principal objective always has a bearing on other benefits. For example, a fire set in a forest to reduce debris and understory trees will result in more grasses, flowers, and browse and thus improve conditions for wildlife. A fire set in chaparral to improve wildlife habitat will also reduce fuels. A fire set in woodland-grass chaparral to improve livestock grazing may also result in better wildlife habitat as well as increase water flow from springs (Biswell and Schultz 1958).

Prescribed Fire Use in Forests

Much of my burning has been done in ponderosa pine for two reasons: first, the pine needle fuels are highly flammable and will burn under cool, moist conditions, at a time when many of the other fuels will not carry fire; and second, a majority of the pine forests are full of dead fuels and dense thickets of brush where the benefits from burning can be very high. Some 100 years ago ponderosa pine forests in California were considered fire sub-climax (Biswell 1959). They were open and park-like with the mature trees large and spread far apart (fig. 3). The smaller

Figure 3--Natural forest pattern created by frequent low intensity fires.

trees were growing in even-aged groups here and there where the death of mature trees had created openings; a distribution pattern brought about by frequent low intensity fires. Those frequent low intensity fires permitted little opportunity for undergrowth or litter to accumulate before another one would consume them. Thus the fires prevented the build up of fuels as well as holocausts at some later date.

As a result of fire exclusion over the past 75 years or so, two great changes have taken place in the forests. First, shade tolerant trees such as white fir and incense-cedar have increased in the understories, along with some of the chaparral shrubs; and second, large quantities of debris, some from logging operations, have accumulated on the forest floor. These conditions make prescribed fire greatly needed and highly beneficial (fig. 4).

Figure 4--Upper: brittle limbs can cause vast quantities of fuels to accumulate at the base of Big Trees. Lower: heavy fuels at the base of young Big Trees.

One should not have to mention the fact that adequate fire protection is the first essential in good forest management. This is absolutely essential if the forests are to be managed and preserved for timber growing, water production, landscape, recreation, and wildlife. However, at the same time, if prescribed fire is harmonized with management and is used as a tool, the fire hazards will be minimum, protection easier, and effectiveness of

fire control improved (fig. 5). The danger from wildfires and the expense of fire control will be much reduced. A pronounced

Figure 5--Same place as the lower picture in figure 4 but with the fuels removed from against the trees and burned in place.

demonstration of this occurred in late August, 1962, when a severe wildfire moved into the Hoberg area. It was nearly a perfect demonstration. One of the headfires of a severe 11,000 acre wildfire raced about 7 miles in 4 hours into one of the areas that had been prescribe burned. On the outside it had been crowning and jumping, and it burned the needles off the trees and killed nearly every tree in its path. But when the fire reached the area that had been prescribed burned, it went to the ground, became relatively calm, and progressed rather gently through the pine needles on the ground. After this happened the fire was easily controlled and no damage was done (Biswell 1963, 1967). It was the use of prescribed fire in reducing fuels that saved the resort. The resort had facilities for sleeping 500 and feeding 1,100. It was valued at perhaps $2,000,000.

Prescribed fires in forests may be used also to restore fire as a natural ecological process in parks and reserves (Kilgore 1970); to improve conditions for wildlife (Lawrence and Biswell 1973); to improve aesthetics (Cotton and Biswell 1973); to prepare seedbeds for reproduction (Kilgore and Biswell 1971; Biswell and Weaver 1968); and to maintain fuel breaks (figs. 6, 7, 8).

Prescribed Fire Use in Chaparral

Chaparral brushlands have been looked upon chiefly as valuable for game and watersheds (Biswell 1974). Our studies on the use of fire in chaparral were directed toward two main objectives: first, to determine the extent to which deer populations respond to opened up brush stands; and second, to determine the burning technique for using fire in chaparral. These studies were

Figure 6--Above: prescribed fire moving down slope with air temp. 47°F, humidity 81%, fuel stick moisture 18%. Below: fire in white fir debris with flames about one ft. high; air temp. 53°F, humidity 35%, fuel moisture content 8%. Fuel dry at the soil surface.

Figure 7--White ash showing after one prescribe fire in big trees forest. Duff removed from the base of the big tree on the left to avoid scorching of the bark.

Figure 8--Fuelbreak maintained by prescribed fires. Burned in fall both in 1975 and 1976.

carried out in chaparral areas in Lake County. The brushlands there form two cover types; one in which chamise predominates, and one containing a mixture of broadleaf shrubs and trees, known as mixed chaparral. The chamise occurs mainly on south-facing slopes and drier sites, while the mixed chaparral is found on the more mesic, north facing exposures and in ravines.

The technique in burning was to set fires with a flame thrower at the base of south-facing slopes in the highly flammable fuels and let the fire burn uphill until it goes out at the top of the hill or next to less flammable mixed chaparral (fig. 9). The general objective was to reduce the cover in spots to create openings. Unlike surface fires in the understory of trees, those in chaparral burn the entire cover of shrubs.

Figure 9--Low intensity fire in chaparral, burning upslope in spring time when the surrounding grasses are still green.

An opened area of chaparral was compared with one of dense, untreated brush as a control (fig. 10). Counts of deer in opened brush gave a summer population density of about 98 per sq. mi. after the initial brush manipulation treatment. This rose to 131 the second year, and then dropped to 84 the fifth and sixth years. In the dense, untreated brush there was a summer density of only 30 deer per sq. mi.. Ovulation rate in adult does was 175% in opened brush and only 82% in untreated brush. Deer weights were higher in opened brush than in untreated (Biswell et al. 1952).

Figure 10--Chamise chaparral improved for wildlife by upslope strip burning.

Prescribed Fire Use in Woodland-Grass Chaparral

There are livestock ranges where chaparral species have increased in abundance to lower grazing capacities. Ranchers use fires to remove the brush to make more space for grasses and to reduce shrub competition (fig. 11). Dry grass is the fuel that carries the prescribed fire, and, of course burning is done during summer (fig. 12). The objective is to remove as much of the brush as possible. Success depends somewhat on whether the shrubs are sprouters or non-sprouters. Two fires close together in non-sprouting chaparral can give fantastically good results. However, in sprouting shrubs the results are not as good since the roots are not killed and they give rise to new plants. Very often spring flow increases after fires in chaparral and woodland-grass chaparral.

Figure 11--Prescribed burning in woodland-grass chaparral.

SELECTION AND TRAINING OF PERSONNEL FOR PRESCRIBE BURNING

Special attention must be given to the selection and training of personnel for use of prescribed fires in management. Selection should be based on the following personal qualities: good judgement, keen observation, high power of concentration, display of energy, interest in the work, and above all, patience. They do not need a BS or PhD degree. Those selected as candidates should be interested and receptive to training and study in fire ecology. This is a study of effects of fire on the environment and the interrelationships of plants and animals therein (E. V. Komarek). Special courses should be developed for this purpose and emphasis placed on integrated resources management. A clear distinction should be maintained between the effects of wildfires and prescribed fires. Topics to be studied might include such things as the significance of differences in flammability of fuels, and basic interrelationships between fire behavior, weather, fuels, and topography.

The most important step in training personnel for prescribed burning is to give them field experience under supervision. This should be one full season of burning--fall and spring--and might be 40 to 50 days in order to qualify as head of burning programs and to lead burning crews.

After prescribed burners are selected and fully trained, their full time activity should be related in some way to the use of fire in management.

It would be difficult to name a half-dozen people in all of California who are qualified for successful work in prescribed burning. As yet people simply have not been selected and trained for this specialized activity. Many fire control officers consider themselves qualified but they actually are not. Firefighters are superbly trained to control wildfires. On the other hand, prescribed burners are selected and trained to set and manage fires to obtain certain planned benefits. The two are very different.

Figure 12--Before and after one prescribed fire in woodland-grass chaparral.

GUIDELINES FOR PRESCRIBE BURNING

The specifics of using fire as a management tool vary with the kind and type of vegetation, and the benefits to be obtained. Van Wagtendonk (1972) developed refined burning prescriptions for Yosemite National Park; Schimke and Green (1970) wrote on prescribed fire for maintaining fuelbreaks in the central Sierra Nevada; and Biswell and Walfoort (1977) have prepared guidelines for the application of prescribed fires in sequoia and mixed conifer forests. All of these pertain to fire use in forests.

Guidelines cover such subjects as the objectives in burning; the flammability of fuels; natural and artificial fire breaks; qualifications of those who burn; conditions of weather, fuel moisture, and slope under which burning is done; and the actual setting

of fires and managing the flames to obtain the rate of spread and intensity of heat desired.

If prescribed fire is to be used successfully, careful attention must be given to planning and carrying out of the burns. Those in charge must be well trained for the work. A burning crew should consist of four people. With each member on leave two days per week, this leaves three on the job at anyone time, one leader and two helpers. In heavy fuels the crew of three should plan to burn not more than about 15 acres per day. The fires move slowly, and constant patrolling is necessary. After the fuels have been reduced to a low level, the acreage burned per day can be greatly increased. If there is more than one crew, they should work in close proximity and coordinate the work.

Equipment consists of fire tools, such as McClouds or California fire tools; backpumps; and a driptorch. Planning should be aimed at handling the fires without heavy equipment.

ALTERNATIVES TO PRESCRIBE BURNING

I see no satisfactory and economical alternatives to the use of prescribed fires in forest and brushlands management for fuels reduction and the other benefits discussed. Special treatments may be needed in some brushlands to make burning more useful and economical. For example, mashing the brush with bulldozers on slopes that are not too steep can increase the flammability of the fuels, and make it possible to burn them under conditions too cool and damp to ignite the surrounding vegetation (fig. 13).

Figure 13--Chaparral mashed with a bulldozer, dried and ready to be burned under cool, moist conditions.

There are not very many chaparral brushlands where I would want to rely entirely upon mechanical equipment, herbicides, and goats to reduce fuels. However, if the objective is to destroy the brushland and convert to grass, and the slopes are not excessively steep then those methods may be satisfactory. My own work in chaparral has been concerned with the maintenance and management of that plant cover. Much of the chaparral is on slopes too steep for mechanical equipment, and I would not want goats on it in the winter time; soil erosion would be too great. Mechanical equipment can be used very well on woodland-grass ranges where shrubs have increased and the objective is to remove them to favor grasses. However, this must be done with caution on steep slopes.

DISCUSSION

We are faced with a dilemma. We want good fire protection, but at the same time we would like to have it without the destruction and expenses associated with intense wildfires. What is the answer? I think we must work in harmony with, and not so much against nature. We must use fire carefully to simulate those low intensity lightning fires that once structured the forests and brushlands, removed fuels, and made the vegetation more resistant to fires and holocausts. This can be done through prescribed fires.

As pointed out in the text, there is much resistance to the use of fire. This is mostly in government and other professional agencies; it is not as much in the public as some would like to believe. There is much confusion, not so much controversy, about the use of fire, because so many people talk and write about it who are not trained and experienced in the science and art of prescribed burning. They hardly distinguish between intense wildfires in the wrong places at the wrong time, and low intensity prescribed fires set in selected places and managed for beneficial purposes.

The policy of virtual fire exclusion, which permitted some slash burning, was adopted long ago. Some people claim that this policy has been in effect so long that it cannot now be changed. They say there is too much fuel, too widespread; therefore, it is too dangerous to attempt burning. Furthermore, the acreage is so vast that it could never all be covered.

Actually, the policy of virtual fire exclusion is not bad. The mistake lies in not using low intensity fires in selected places to keep the fuels down to a reasonable and tolerable level. Thus, prescribed fire does not take the place of fire exclusion, but it can supplement it and make fire control easier and less expensive, and wildfires less destructive of resources.

I have heard that some people resist the use of fire because they don't want to "rock the boat". The thinking goes like this: We don't want fires; they get started by lightning, an act of God, or through someone's carelessness, or perhaps by an arsonist; we try our best to put them out; the weather was unusually dry and windy; it was too bad that the fire occurred; it shows a need for more personnel and equipment, and more money is sought while the "iron is hot."

Under the policy of virtual fire exclusion, fire management is easy. On the other hand, if prescribed burning is tried and a fire gets out of control, it causes all kinds of problems. So it is better to continue as we are and not try using such a dangerous tool as fire.

The blame for intense wildfires is usually placed on the smoker, careless camper, arsonist, or lightning. Seldom is the blame placed on our own carelessness in letting the fuels build up to such dangerous levels (fig. 14).

Figure 14--Heavy debris following logging operation. A severe wildfire close by burned 2000 acres. The fire was blamed on a careless smoker. Should'nt the stewards of the land have taken part of the blame for having such fuels in the forest?

The wildfire problem in California is very severe and critical. This cannot be over-emphasized. I don't know exactly what to recommend as a cure. One approach would be to put more emphasis on prescribed burning and use it a great deal more. This might be done if Congress and the state iegislature each reduced appropriations for fire control by $1,000,000 each year for 15 to 20 years and specified that this be used for prescribed burning, mainly in forests. If this were done perhaps we could begin to get on top of the wildfire problem. This would not be reducing overall appropriations for fire, but it would be a redirection of emphasis. Under this plan, I think more timber could be grown, conditions improved for wildlife, aesthetics improved, and camping and other recreation made safer. In my judgment all resources would be benefited (fig. 15).

Figure 15--Managed with prescribed fire, our goal: Lower fire hazards and less cost in fire control, more timber, more forage and browse, better water supply, easier management, more flowers and improved aesthetics.

I believe that fire management should be divided into two divisions--fire control and fire use. Fire control should be the organization that puts out fires; fire use should be the organization that uses prescribed fires in selected places and under conditions where the fires can be managed for beneficial purposes. Thus, the objectives of the two organizations would be entirely different. Training of personnel could be much more complete and effective than at present. I have observed that people trained expertly in fire control often know very little about prescribed burning; but this may be a result of lack of training in prescribed fire use.

The prescribed burner should be an ecologist. He should know the fuels and their flammability, and he should know the species and their tolerance to fire. If in forestry, he should have good training in silviculture and forest management. I would not expect all of this of the person trained expertly in fire control.

RECOMMENDATIONS

1. A program of selecting and training personnel in the science and art of prescribed fire use should be started and pursued vigorously.

2. Fire management should be divided into two units, fire control and prescribed fire use. They should be seperate and of equal rank. Thus, emphasis would be redirected from fire control toward prescribed fire use.

3. Prescribed fire use demonstration areas should be established. These should be at least 2000 acres each, one on every ranger district of the national forests, on each of the larger state forests, and at Blodgett Forest of the Univ. of Calif.. The National Parks and Calif. Dept. of Parks and Recreation are carrying forward with prescribed fire use, and already have demonstration areas. However, more and larger ones are needed.

4. In master planning, I suggest that one forest in southern California, e.g., the Cleveland, and one in northern California, e.g., the Stanislaus, be staffed with personnel who have prime interest in prescribed use of fire; this would be from the forest supervisor on down. They should be left alone to pursue an active program in prescribed burning.

5. Consideration should be given to passing a law which would require land managers to keep fuels and fire hazards below a certain, tolerable level. With this, it would be unlawful to have fuels such as those in figures 2, 4 lower, and 14.

6. Research on low intensity fires and environmental effects of fire exclusion should be conducted on the demonstration areas. Research on effects of intense wildfires should be minimized since it has been proven convincingly, over and over, that they can be extremely detrimental to the environment and costly to control. Prescribed fire (especially broadcast burning in the understory of trees) is a new approach to the wildfire problem. It holds great promise for the future.

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FUEL REDUCTION WITHOUT FIRE--CURRENT TECHNOLOGY AND ECOSYSTEM IMPACT[1/]

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Abstract: Alternatives to using fire for fuel reduction are attractive because of environmental and legal considerations. Costs are comparable when all expenses of fire use are included. Bulldozers with blade or brushrake are used to clear and pile brush; hand labor is costly but appropriate in sensitive areas. Anchor chains are used to crush brush, usually so that later burning will be safer. The brushland disk and roller chopper can chop brush and mulch it into the soil. To restrict brush regrowth following any clearing, herbicides, especially 2,4-D, have long been used, but there is renewed interest in using browsing by goats for this purpose.

Key words: Chaparral, fuel modification, brushland disk, anchor chain.

INTRODUCTION

Fuel reduction without any use of fire has not been the usual practice in most brush-producing areas of the United States. Instead, various mechanical, or sometimes chemical, treatments are frequently used to prepare the fuel for broadcast or pile burning. Following prescribed burning, the land manager may use chemical treatments, or perhaps browsing by livestock, to keep the brush from rapidly reoccupying the site. However, many land managers favor using alternatives to broadcast burning of standing brush because they believe these to be no more expensive, less damaging to the environment, and subject to minimal legal liability. Also, the National Clean Air Act authorizes State and local air resources boards to regulate or prohibit fire use on any given day, and is additional encouragement to reduce fuel without using fire.

1/ Presented at the Symposium on Environmental Consequences of Fire and Fuel Management in Mediterranean Ecosystems, Palo Alto, Calif., Aug. 1-5, 1977.

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In California, we have about 11 million acres (4.4 million ha) of brushland and 9 million acres (3.6 million ha) of woodland containing varying densities of brush. The chaparral also extends into the interior valleys of southern Oregon, and 200 miles (320 km) into Baja California; Arizona has at least 3.2 million acres (1.3 million ha) (Cable 1975). Other kinds of brush occupy 50 million acres (20.2 million ha) in non-Mediterranean climates in the American Southwest. Modification or reduction of these vast brushfields in any significant quantity requires heavy equipment. This review concentrates on the methods of fuel modification with heavy equipment that are being used in California at the present time.

CLEARING AND PILING BRUSH FUELS

Under most conditions, clearing and piling brush, by machine or by hand, is the favored method for fuel modification. Although the clearing may be followed by prescribed burning, leaving the piles may have beneficial effects on wildlife.

Bulldozers

The bulldozer with straight blade has long been the standard equipment for clearing and piling woody fuels. The dozer has the necessary

power to remove even large trees, and is rugged and dependable. It is better adapted to working on irregular terrain and in heavy brush than any other large equipment. Use of the bulldozer is sometimes discouraged, however, because of excessive disturbance of the topsoil and mixing of soil with the piled brush. The mixed-in soil makes burning the brush piles difficult, and there is danger of flare-ups days or weeks later. Skilled tractor operators who are not working to cover a maximum area can almost eliminate this objection. We recently contracted for clearing of 30 acres. The tractor operator was instructed to keep his blade above the soil surface and not to disturb the soil. As a result of his careful work, brush and trees were pushed into windrows, and the only soil distrubance was where root systems were pulled free of the soil. If a direct attempt is made to uproot root crowns, the soil will be thoroughly disturbed.

Large tractors will clear and pile an acre of brush per hour in light fuel, and perhaps 0.6 acre (.2 ha) of very heavy brush if the slope is no greater than 25 or 30 percent.

After clearing by bulldozer, there is generally sprouting from the remaining root crowns and germination of brush seedlings. Thus, follow-up treatment is needed to prevent the site from reverting to brush in 5 to 7 years.

Brushrakes

Piling or windrowing is usually more effective, and ecologically acceptable, where a rake-type implement is used to supplement or replace the dozer blade.

Brushrakes have a moldboard similar to that of the dozer blade, but teeth, 9 inches (23 cm) or more apart, extend below and forward. On some brushrakes, the teeth may replace the moldboard (fig. 1). Many sizes and variations are available (U.S. Forest Service 1971). The teeth increase the efficiency of direct uprooting and piling, and reduce the quantity of earth moved. If the soil is dry and sandy, it can be rapidly sifted out. If it is moist, or fine textured, separating soil from plant material is difficult.

Brushrakes mounted on D7 or D8 tractors (180 to 270 net HP) can clear and pile 1/2 to 1-1/2 acres (0.2 to 0.6 ha) per hour in light fuels, and from about 1/3 to 2/3 acre (0.14 to 0.27 ha) in heavy brush. Direct costs range from \$30 to \$65 per acre (\$74 to \$161 per ha). Steep slope reduces speed and thus increases the cost.

Figure 1--Brushrakes uproot and pile brush while moving a minimum of soil.

The tractor with brushrake has one serious disadvantage--it leaves the soil loose and sometimes channeled and subject to raindrop and runoff erosion during high intensity storms.

Hand Clearing and Piling

Hand labor is generally the most costly method of clearing brush, but at times it may be the only practical one. Steep slopes, loose soil, rock outcrop, or management considerations may make mechanical methods impractical, and if prescribed burning is not suitable, hand clearing is the only alternative. Hand labor is desirable for clearing around or through special places such as archaeological sites, areas containing distinctive plants, or areas where aesthetic effects are important. It results in less disturbance than any other fuel modification method. In California during the 1950's and 1960's, considerable fuelbreak was cleared by hand because low-cost inmate labor was available. Today, such labor is much less commonly available. Much of the hand clearing today is done by firefighting crews when they are not doing higher priority work.

When hand crews are used, they generally cut and pile the brush in windrows for later burning (fig. 2). Tools in common use are the

chain saw, brush hook, and pulaski. Sometimes pruning saws and shears are used. A powered brush cutter of considerable promise was used on some Forest Service jobs. A motor carried on the operator's back drove a flexible drive shaft that ran through a tube 3-1/2 (1.1 m) to 4 feet (1.2 m) long, turning a circular saw at the end. Without such power tools, hand cutting would be considerably more expensive.

On many hand cutting projects, freshly cut brush stumps are treated with herbicide to reduce sprout regrowth. One technique required mounting a large sponge on the end of the looped tube on a drip torch (fig. 3). The sponge absorbed the herbicide, and covered the cut surface when pressed against it. There is almost no waste nor drift with this method.

The rate of production for hand cutting, piling, and stump treatment varies from about 100 man-hours per acre (247 per ha) in light brush to an average of 275 man-hours per acre (680 per ha) in heavy brush. At $5 an hour, cost is from $500 to $1,375 per acre ($1,235 to $3,400 per ha). Costs may be higher under adverse working conditions.

Figure 3--A drip torch, normally used for spreading prescribed fire, makes an excellent herbicide dispenser when a sponge is added.

Figure 2--Hand cutting and piling of brush is expensive, but disturbs the site less than other clearing methods.

CRUSHING BRUSH

Under certain conditions of terrain, brush type, and management objective, the indicated treatment for chaparral is to crush and compact the brush. This may be done to prepare for safe prescribed burning, to clear land following wildfire, or to stimulate brush sprouting within the reach of browsing animals. Brush to be crushed must be mature; young limber brush merely springs back into place.

The Bulldozer

The bulldozer with straight blade is sometimes used to crush and compact mature brush, and could be used more widely for the purpose. It is effective in all mature vegetation types, and on slopes to about 35 percent. The crushing is accomplished with minimal disturbance of the soil. Two to three acres (0.8 to 1.2 ha) per hour can be crushed on terrain up to 30 percent slope, in heavy brush, at a cost of $15 to $24 per acre ($37 to $60 per ha). If terrain is gentle, mounting a rail on the dozer blade, as was done recently on the Los Padres National Forest, can nearly double production.

For crushing, the blade height varies depending on brush height, density, and brittleness of the brush. From 1 to 1-1/2 feet (30 to 46 cm) is the norm. Crushing during the season when vegetation is low on moisture is usually more effective than during the spring when moisture is high.

The Tomahawk crusher (fig. 4), which was designed for breaking up roadbeds, improves the crushing action of crawler tractors, particularly between the treads. It is frequently mounted on the dozer blade, or sometimes behind the tractor.

Anchor Chains

Chains have been used in land clearing for many years, but not until surplus Navy anchor chain became available were they used much in chaparral modification. Such chains weigh from 40 to 90 pounds per linear foot (60 to 134 kg/m), and lengths of chain vary from 90 to 270 feet (27 to 82 m). The longest lengths have been used in flat or gently sloping terrain free of large rocks and trees. Shorter chains are used in mountainous terrain. The effective swath width averages about half the length of the chain.

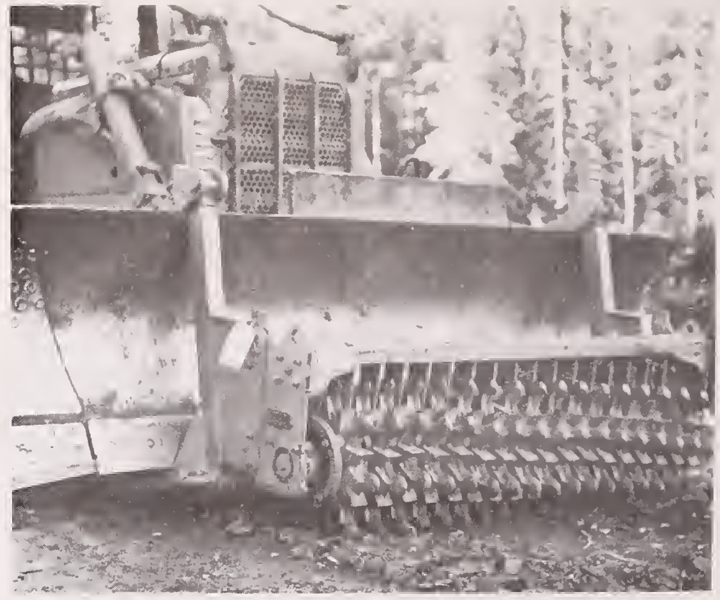

Figure 4--The Tomahawk compactor-crusher breaks up brittle fuels and mulches part of them. This reduces the rate of spread and resistance to control of fire burning in such fuel.

The smooth chain is useful for crushing mature chaparral, or small trees such as pinyon pine or juniper (*Juniperus* sp.). If the objective is to uproot as much brush as possible, the chain is frequently modified by welding steel bars at 90° angles to each other on the chain links (fig. 5). The modified chain "walks," rolls, and slides along, crushing, chopping, and sometimes pulling out much of the brush.

Figure 5--Anchor chains are frequently modified by welding steel bars across the chain links. This increases uprooting of brush.

Where terrain is uniform and slope is no greater than 30 to 35 percent, two passes, one in each direction, with the chain between two large tractors, can crush from 2 to 4-1/2 acres (0.8 to 1.8 ha) per hour in light fuel and from 1-1/2 to 3 acres (0.6 to 1.2 ha) per hour in heavy fuels. Using D8 sized tractors, direct cost might run from $20 to $60 per acre ($49 to $148 per ha). If one pass of the chain is sufficient, these costs are reduced by nearly half.

Chaining, or cabling, is used extensively throughout the Southwest. Two tractors dragging a chain between them in both directions usually uproot most pinyon pine or juniper, or dead or live mesquite (*Prosopis*) trees or shrubs, if stems are stiff enough. Some followup raking or prescribed burning usually follows the chaining (Martin 1975, Paulsen 1975). In the south Texas plains, double chaining followed by raking and stacking for burning was the most effective treatment or combination of treatments tested for preparing seedbeds (Scifres and others 1976).

The "ball and chain" crushing technique was developed to crush brush on slopes steeper than 35 percent, where other equipment operates with difficulty, if at all. Equipment commonly used is a light-to-heavy anchor chain, and a steel marine net float, or buoy, 5 feet (1.5 m) in diameter (fig. 6). Weight of chain and ball should be proportional, otherwise the ball will not drop down the slope.

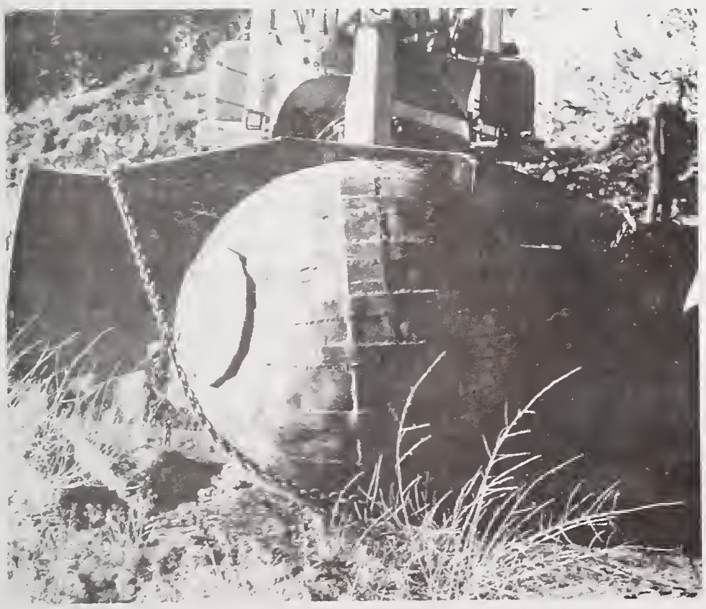

Figure 6--The ball used in ball and chaining, is a Navy buoy which has been reinforced with additional steel plating, then filled with water and sand.

In use, the buoy or ball is filled with water, or gravel, or sand plus water. A chain of 90 to 150 feet (27 to 46 m) is fastened to the ball, and the other end to a large tractor. The ball is pushed so that it drops down a slope greater than 30 percent. The tractor traveling along the ridge above drags the ball and chain, crushing a strip about half the chain length. Unlike all other forms of fuel modification without fire, the ball and chain is more efficient on steep than on gentle slopes (Roby and Green 1976). Average production on 20 to 30 percent slopes was 0.8 acre (0.32 ha) per hour for two or more passes, but it was 1.2 acres (0.5 ha) on slopes in excess of 50 percent.

CHOPPING AND MULCHING

Where prescribed burning is not planned, equipment is needed to chop or shred the brush and reduce it to a mulch that is at least partially incorporated into the soil. The heavy brushland disk is widely used in California and roller-choppers are used some on gentle terrain. Many other pieces of equipment have been tested, but equipment breakage has been high in our rocky sites, steep slopes, and heavy tough brush.

Brush Disks

A variety of weights and sizes of offset harrows or tillers, commonly called brush disks, are available from several manufacturers. The disks in common use have two gangs of blades that can be opened to offset each other. As they are pulled forward, they chop or cut and mulch much of the smaller brush, uproot small root crowns, and bring many root burls to the surface. The disk is particularly effective on chamise chaparral, where single disking of heavier brush leave the site ready for drilling seed with the rangeland drill. In very heavy brush, one pass of the disk prepares for broadcast burning, although the method is not as economical as with other crushing practices.

Disks in use today weigh from 6,000 to 12,000 pounds (2,720 to 5,450 kg) and are 8 to 12 feet wide (2.4 to 3.7 m). Disk blades are commonly 32 or 36 inches (81 or 91 cm) in diameter. Disks weighing 10,000 pounds (4,530 kg) or more require 180 to 270 HP for efficient operation, or D7 or D8 size tractors.

The disk does not remove the topsoil, but does stir and loosen it to a depth of 8 to 16 inches (20 to 41 cm) (fig. 7). The effect can be bad if high intensity storms occur, or it

can be good if soil was crusted, compacted, or had been made water repellent near the surface by hydrophobic substances from shrubby plants. The loosening could then increase infiltration. Brush should be disked on the contour and not parallel with the slope, which will encourage erosion. Efficient contour disking is limited to 30 to 35 percent slopes.

Figure 7--The brushland disk chops and mulches light to medium brush with one pass, leaving the soil loose and ready for drilling with the rangeland seed drill.

On National Forests in California, disking has frequently been used to reduce fuel volume and continuity in preference to crushing and burning. This has required one pass of the disk in light brush, and three to five passes in our heaviest brush, to reduce the fuel continuity to the satisfaction of fire control people. The rate for the first pass has generally been about 1 acre (0.4 ha) per hour. Succeeding passes were up to three times as fast, and this economy has sometimes encouraged unnecessary disking to make the disked brushfield appear clean. Costs of disking have been about $45 per acre ($111 per ha) for one pass of the disk in light brush to $110 per acre ($272 per ha) for three to five passes in the heaviest brush.

Roller Chopper

The roller chopper is basically a large drum lying on its side, around which a dozen or more long steel blades have been welded or bolted parallel to the long axis. An axle through the drum, and a draw bar attachment, enable it to be towed either singly or double in tandem. Several models are available.

Widths vary from 4 to 16 feet (1.2 to 4.9 m), but the most practical for our work and conditions are models 8 to 10 feet (2.4 to 3.0 m) wide. The single drum model in this width class weighs about 18,000 pounds (8,170 kg) when filled with water. In use, the roller tends to lift itself up onto a blade, then fall forward onto the next blade, cutting or breaking brush as it does so. The debris produced by the roller chopper is mulched into the soil, or left on the soil surface. This tends to reduce erosion potential, and allows for nutrient recycling. In the tandem model, which is commonly used, the drums are aligned so that each drum cuts or shears the brush from a slightly different angle.

Roller choppers have worked well in medium-density chamise-coastal sage brush with stems less than 2 inches (5 cm) diameter, one pass sufficiently reducing the fuel that prescribed burning was judged unnecessary. In medium to heavy brush, two passes chopped about 70 percent, mostly the fine materials, and mulched it into the soil.

A serious disadvantage of the roller chopper in much of the chaparral is that it cannot be worked efficiently on slope gradients greater than about 15 percent. It tends to slide sidewise down the slope. Another shortcoming is that it kills almost no shrub crowns, so regrowth is immediate and abundant.

Flails

Other kinds of equipment have been suggested or tested for shredding brush, but they have not been accepted for general use in the chaparral. Such equipment frequently uses hammers, chains, or other flails rotating at high speed to shred the brush. The Tritter Model 260 has been used in Australia for many years, and appears to have application in chaparral. A front-end flail cutter, the Tree Eater, was designed to masticate woody vegetation from shrubs to trees, and it did this quite well, at rates of up to an acre (0.4 ha) per hour. It was limited by terrain, however, and initial cost and maintenance costs were high (U.S. Forest Service 1970).

Root Plowing

In the American Southwest, fighting brush is a major concern. Ranchers are interested in reduction of brush density, retardation of regrowth for as long as possible after treatment, and improvement of forage quantity and quality.

In general, they have obtained the most drastic reductions in brush cover and density by the most severe mechanical treatments--those that disturbed the soil and removed the roots of the brush plants. Root plowing, combined with brush raking or roller chopping, was frequently the most effective combination of treatments for reducing brush density (Drawe 1977, Stuth and Dahl 1974). In root plowing, a heavy blade is pulled horizontally at a depth of 8 to 18 inches (20 to 46 cm) below the soil surface by a crawler tractor. Shrubs are severed below the root crown or sprouting bud zone (Pond and Bohning 1971).

Although root plowing is the most effective mechanical method for controlling shrubs (Cable 1975), it has not been used much in California because it requires that soils be deep and free of rocks. Gullies and steep slopes also prevent root plowing. San Diego County Department of Agriculture personnel did weld a root cutter bar onto the teeth of a brush rake and operated it about 6 inches (15 cm) below the surface. It severed roots of chamise and other small brush where rock did not interfere (County of San Diego 1973).

PREVENTING BRUSH REGROWTH

After aboveground portions of brush plants are removed, no matter what the method, most sprouting species produce growth from buds in the root crowns, sometimes in as little as 10 days after treatment (Plumb 1961). Seedlings, frequently thousands per acre of *Adenostoma*, *Ceanothus*, or *Arctostaphylos*, add to the regrowth, and within 5 to 7 years brush crowns are closing again. Control of this regrowth has been the most persistent and perplexing problem in manipulating vegetation, in converting brush to new vegetation cover, or in maintaining light stands of woody fuel.

Herbicides

Treating brush regrowth with herbicides has been standard practice since phenoxy-type herbicides were released following World War II. The herbicide 2,4-D (2,4-dichlorophenoxyacetic acid) has been and still is most commonly used, but a mixture of 2,4-D and 2,4,5-T (2,4,5-trichlorophenoxyacetic acid) may be applied to certain hard-to-kill species. These and other phenoxy herbicides are effective at light rates against most brush species and other broadleaved plants, but do not seriously damage grasses. Thus, they can be used to control brush regrowth while grasses are being established (fig. 8).

Figure 8--Following a wildfire, the area on both sides of the brush was treated with herbicides and converted to grass.

Picloram (4-amino-3,5,6-trichloropicolinic acid) is also proving to be effective for controlling brush species without damaging grasses both as a foliage spray and applied directly to the soil.

Herbicides must be used on wildland areas in accordance with Federal, State, and local regulations. These have evolved from long experience in use of herbicides, and from study of all other evidence of their possible deleterious effects. Various recent analyses cited by Green (1977) show that herbicides approved for use against brush species, and applied according to label instructions, are not a significant hazard to the wildland environment.

If herbicides are properly applied, and applications are repeated for up to 3 years, most shrubs can be controlled at costs generally below those of other brush control methods (Bentley 1967, Murphy and Leonard 1974).

Browsing Animals

A second tool for prevention or control of brush regrowth may prove to be browsing animals. Deer have controlled regrowth where the quantity was limited, but not where fuel modification has been extensive. Sheep and cattle have been the dominant livestock in California, but neither browse much. Goats are the most efficient domestic converters of woody plants into animal products (Naveh 1972). Their taste for shrubs

may be even greater than that of deer, and goats select much more browse in their diets than sheep or cattle (Merrill 1972). They have been used extensively to prevent encroachment of brush and to clear brush in Texas (Huss 1972, Gray 1959, Merrill and Taylor 1976) and elsewhere, but references to such use in California are meager (Elam 1952, Flynn 1973), even though there is a goat industry centered in Amador and Calaveras Counties.

Goats as a tool for brush control are now getting attention from the Forest Service and its cooperators in California. In 1973, a study was established in the Sierra Nevada foothills, about 50 miles (80.4 km) southeast of Sacramento. Brush was cleared from 30 acres (12 ha) which were stocked a few months later with Angora goats at two rates--heavy and moderate. After 4 years, the goats have almost eliminated woody plants--*Quercus wislizenii, Heteromeles arbutifolia, Arctostaphylos viscida, Rhus toxocodendron*--in the heavily grazed and browsed pasture. In the moderately grazed pasture, shrubs have been so heavily browsed that about three-fourths of the brush plants are dead. Annual grasses and forbs were not damaged.

In 1976, the Cleveland National Forest in San Diego entered into an agreement calling for a herd of Spanish goats to browse on fuelbreaks. After 2 days in a 2-1/2-acre (1 ha) enclosure, where regrowth was 3 to 4 feet (0.9 to 1.2 ha) tall, 400 goats had taken 95 to 98 percent of leaves and small twigs from *Cercocarpus betuloides* and about 93 percent of *Quercus dumosa*. The two species made up about 80 percent of available browse. There was heavy use of *Adenostoma fasciculatum* flowers, but little browsing of twigs. *Arctostaphylos glandulosa eastwoodii* and *Eriogonum fasciculatum* were very lightly browsed. *Ceanothus greggii* and *C. leucodermis* were lightly browsed. This pattern of selectivity has persisted where the goats have had free choice.

When the enclosures were combined with others similarly browsed, and used for holding the goats at night, all unbrowsed species were quickly stripped of leaves and small twigs. This lesson is now being applied elsewhere on open fuelbreak, where the goats are being concentrated by herding to see if younger regrowth of all species will be uniformly browsed.

Browsing by goats is not without problems, such as predators, unseasonable cold weather, lack of qualified herders, and the fact that fuelbreaks are not always economic browsing units. Nevertheless, goats appear to be a promising tool for maintaining brush fuels at a low volume after initial clearing by some other method.

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PRESERVATION IN FIRE-TYPE ECOSYSTEMS [1]

David J. Parsons [2]

Abstract: The preservation of national parks or equivalent reserves as naturally functioning ecosystems requires that fire be allowed to play its natural environmental role. In many cases this will require an integrated fire management program which includes the use of naturally ignited as well as prescribed fire. A review is made of the status of management programs in the world's Mediterranean-climate fire-type ecosystems. Special attention is given to an on-going integrated fire management program in Sequoia and Kings Canyon National Parks, California.

Key words: Preservation, fire-type ecosystem, prescribed burning, fire management, Sequoia and Kings Canyon National Parks.

INTRODUCTION

The concept of preserving large areas as examples of naturally functioning ecosystems first received widespread attention in the latter half of the 19th century. In 1872 Yellowstone was established as the world's first national park. Before the turn of the century other national parks had been established in Canada, Australia, New Zealand, South Africa, Natal and Mexico as well as in the western United States. Today, with national parks or equivalent reserves found throughout the world, management policy in most such areas is aimed at maintaining natural ecosystems in a more or less undisturbed state.

The traditional approach to the preservation of natural areas has usually involved the protection of existing resources as if they were inanimate objects. This usually meant that all fires were considered bad and were to be suppressed at all cost. For example, in the United States the policy of suppressing all fires in national parks began in Yellowstone in 1886 and was implicitly incorporated into the National Parks Act of 1916 (Agee 1974). Total fire exclusion was justified by stressing the protection of landscapes rather than processes. It was further supported by claims that fire damages mature trees, kills good forage species, removes nutrients, promotes floods and erosion and destroys shelter and breeding habitat for birds and wildlife (Kilgore 1976). Damage which had been caused by destructive wildfires and indiscriminate burning tended to support these fears. The occasional voice advocating the beneficial effects of controlled burns or low intensity natural fires went unheeded. It was not until the 1940's in the southeast and the 1950's and 1960's in the west that controlled burning policies were first adopted in the United States. Yet, as is true almost everywhere in the world that fire has been used as a management tool, the burning that was carried out was generally done with specific objectives such as land clearance, reduction of fire hazards or improvement of forage (Kayll 1974). Little attention was given to the need to maintain fire as a natural part of the environment.

If national parks and other equivalent reserves are to be preserved as naturally functioning ecosystems it is important that all natural processes be allowed to operate. For fire-type ecosystems it is especially desirable that fire be allowed to run its course. Unfortunately, the hazardous fuel accumulations which have built up during recent years of fire suppression, along with the cultural facilities

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1/ Presented at the Symposium on Environmental Consequences of Fire and Fuel Management in Mediterranean Ecosystems, Palo Alto, Calif. Aug. 1-5, 1977.

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and recreational developments which now exist in many areas, often make it impossible to allow natural fires to burn. This conflict was eloquently addressed in 1963 in the now famous Leopold Report on wildlife management in national parks (Leopold et al. 1963).

The Leopold Report, in discussing conditions in the Sierra Nevada of California stated "...much of the west slope is a doghair thicket of young pines, white fir, incense-cedar, and mature brush - a direct function of over-protection from natural ground fires". The report suggested that through "using the utmost in skill, judgement, and ecologic sensitivity" it should be a goal of the National Park Service to restore the more natural, open forest conditions of the area. It was obvious that fire would have to be restored as an integral part of the environment if these community types were to be preserved. The Leopold Report, with its rather revolutionary attitudes towards fire suppression, was largely adopted as official National Park Service Policy in 1968. The widespread influence of this change in attitude has been more recently reflected in an increasing interest in understanding the natural role of fire as well as its possible management applications in other fire-type ecosystems of the world (Naveh 1974, Phillips 1974).

In this paper I will discuss the use of fire as a management tool to preserve naturally functioning ecosystems. In line with the subject of the symposium I will focus on the world's Mediterranean climate fire-type communities.

FIRE-TYPE ECOSYSTEMS

It is important that managers of national parks and other protected areas recognize that fire plays an essential role in maintaining many natural communities. Nowhere is this more true than in the world's Mediterranean-climate ecosystems (California, the Mediterranean Basin, southwestern Australia, Cape Province in South Africa and central Chile). Periodic fire, both natural and man caused, has played an extraordinary role in the evolution of the plant communities of these areas (Naveh 1974). The hot, dry summers characteristic of Mediterranean type climatic areas typically produce exceptionally low fuel moistures and thus high potential flammability.

Woody plant communities of Mediterranean-climate regions include evergreen forests and woodlands, evergreen shrubs, drought deciduous scrubs and grasslands. Each of these vegetation types has evolved in the presence of fire. Many of the characteristic plant species exhibit specialized fire adaptations. These include the ability to stump sprout, seeds which lie dormant until exposed to intense heat, thick bark, serotinous cones, and other physical and chemical structures which maximize flammability (Kilgore 1973a, Biswell 1974). It has been hypothesized that fire-dependent plant communities burn more readily than do communities less dependent on fire since natural selection has favored the development of characteristics which make them more flammable (Mutch 1970).

The role fire has played in perpetuating fire-type ecosystems has attracted growing attention in recent years. This role includes such vital functions as nutrient recycling, seedbed preparation, control of insect and disease susceptible trees, reduction of fuel buildups, improvement of wildlife habitat and shaping of successional trends. It is clear that if we are to maintain such communities as examples of naturally functioning ecosystems it will necessary to allow fire to play as natural a role as possible. In most cases this will require implementation of a sophisticated fire management program. The growing body of international literature on fire ecology and management (Kayll 1974) together with the success of active fire management programs in several national parks (Kilgore 1975) reflects an increasing concern with this problem.

FIRE MANAGEMENT ALTERNATIVES

Fire management decisions in a national park type setting must be based on a firm understanding of the natural role of fire in the area. Basic information on the frequency, size and intensity of past natural fires, the type and amount of fuel accumulation, vegetation and successional patterns, microclimate and potential fire behavior form a necessary foundation for a successful fire management program.

Once it is determined that fire is necessary to maintain or reestablish the natural ecosystems of an area a decision must be made as to what type of management program to use. Fire management may include the use of fire in its free-burning state or under carefully controlled conditions, when it is called prescribed burning. In either case an active fire suppression program, either at certain times of the year or under certain climatic conditions, may also be necessary.

Natural Fire

The ideal way to restore fire to its natural role would be to permit all lightning caused fires to run their course. In areas where suppression techniques are ineffective, such as in the more isolated parts of Canada, Alaska and Australia, naturally ignited fires often burn uncontrolled for long periods. Since fire has always been a part of these ecosystems and since human lives, personal property and cultural resources are seldom destroyed, there has been little reason to suppress them. This philosophy now forms the basis for programs in several national parks and national forests in the western United States where in certain designated zones naturally ignited fires are allowed to burn (Kilgore 1975). Each fire is continually monitored and evaluated. Suppression action is taken only for public safety concerns, severe resource damage, or if the fire threatens to escape the predetermined zone boundaries. This concept of allowing naturally ignited fires to burn is yet to be tested in most of the world's fire-type communities.

Despite the obvious advantages of such a management policy, it is simply not possible to allow lightning fires to burn in most areas. The hazardous fuel accumulations which exist following many years of fire suppression, threats to human life and visitor facilities, and fear of possible escape usually require that immediate suppression action be taken.

Prescribed Fire

Fire has been intentionally used by man to clear land, improve forage or favor certain species for thousands of years. In most cases little attention was paid to the long range impacts of such burning. In recent years there has been a growing use of controlled, or prescribed burning in an effort to achieve clearly defined objectives. In conducting an effective prescribed burn careful attention must be given to such factors as weather (temperature, relative humidity, wind speed and wind direction), fuel properties (quantity, moisture content and distribution), topography, direction of burning and smoke production. These are the factors which will determine the ultimate impact and success of the fire. For such a program to succeed it is essential that carefully defined limits for each of these factors (a prescription) be developed so that accurate predictions can be made of the probable effects of any given fire (Van Wagtendonk 1974). The state of the art of using prescribed fire as an effective management tool is at different stages of development in each of the world's Mediterranean-climate regions.

Australia

The first large scale controlled burning program in a Mediterranean type climate area was in the highly flammable eucalypt forests of the state of Victoria, Australia. This program, in action since 1960, has involved the use of controlled fire to reduce fuel quantities over large forested areas (Hodgson 1968). The primary objective has been to reduce fuel buildups to the point where wildfires can be effectively contained.

In recent years the burning program in the "fire-type" communities of Australia has been greatly expanded to include extensive areas of other forest and scrub vegetation. Aerial ignition techniques have been effectively used to burn large areas. There has also been a growing interest in understanding the extent to which these fires reflect natural burning patterns. The idea of burning for the purpose of preserving a native vegetation type as well as for fuel reduction is rapidly gaining acceptance. Concurrent research has provided sound documentation of the effects of the burning program on several of Australia's "fire-type" communities (Purdie 1977).

Mediterranean Basin

In the Mediterranean Basin fire has long been regarded as a destructive force to be avoided at all cost (Naveh 1974). However, recent reviews by Naveh (1973) and Le Houerou (1973) have documented the important evolutionary role of fire on both the woody and herbaceous vegetation of the area. Furthermore, recent studies in the coniferous forests and maqui of Greece (Liacos 1973) and the garrigue of France (Trabaud 1973) have shown fire to be a necessary and viable management tool for the perpetuation of these community types. While large scale prescribed burning has not yet been used as an effective tool for perpetuating native Mediterranean vegetation types, the potential and interest appear to be there.

Southern Africa

The effects of fire on many of the vegetation types of southern Africa have been extensively documented (Phillips 1974). While most management burning has been for the purpose of improving conditions for wildlife,

recognition of the importance of fire in perpetuating native ecosystems, including the important game animals, has resulted in a progressive fire management policy in a number of African parks (Austen 1971).

Despite documentation of the importance of fire in maintaining the Mediterranean scrub vegetation, known as macchia, or fynbos, in the Cape Province of South Africa it has only been in recent years that there has been an interest in the use of fire to preserve that community type (Taylor 1977). Fire is currently used in the Cape fynbos region mainly as a management tool to achieve optimum water yield as well as for fuel reduction through maintaining a mosaic of successional communities (F. Kruger, personal communication).

Chile

Less is known about the natural role of fire in the vegetation of central Chile than for any of the other Mediterranean type climate regions of the world. While fire may well have played a significant evolutionary role, it appears in recent years to have been of minor importance in maintaining the typical matorral vegetation. This may be in large part due to extensive grazing and woodcutting, resulting in a relatively open shrub community which will not readily carry a fire (Mooney et. al. 1972). It has also been noted that the summers are cooler and the climate is generally less arid in central Chile than in the world's other Mediterranean climate zones (Aschmann 1973). To date, there appears to have been little interest in using fire as an effective management tool in this area.

California

Significant advances in the use of prescribed burning for the purpose of perpetuating natural ecosystems have been made in the western United States. Many of the forest communities of this area evolved with periodic fire. During the past century efforts to "protect" such areas have resulted in the suppression or elimination of most fires. The result has been a change in successional patterns as well as an increase in fuel accumulation which now threatens to produce unnaturally large wildfires. Prescribed burning programs have been recently instituted in the forested zones of several national parks as a means of reversing this trend. The ultimate goal of such programs is to restore fire as a natural environmental process.

The hazardous fuel buildups which have occurred during the past century in the extensive chaparral shrublands of central and southern California have been a source of growing concern. Such concerns have stimulated extensive studies of the natural role of fire in this community type (Hanes 1971, Mooney and Parsons 1974). These in turn have formed a sound basis upon which to institute prescribed burning programs in many of the chaparral dominated parts of the state (Biswell 1974). The next few years should show significant advancements in this area.

POTENTIAL CONFLICTS

In any fire management program it is essential that potential conflicts with other resource values be fully understood. For example, before a burning plan is approved an assessment of potential adverse as well as beneficial impacts should be made. Care should be taken to evaluate the impact on archeologic, cultural and historic resources as well as endangered species. In many areas attention must also be given to the impact on visitor enjoyment and use patterns. Closures of areas because of potential danger or the obscuring of vistas by smoke are examples of such conflicts. In such cases it is essential that public relations efforts provide a full explanation of and justification for the burning program. In many cases what will be needed will be an increased educational effort directed towards understanding fire's natural role in the environment, including what would happen should fire continue to be excluded.

Atmospheric pollution by smoke must be carefully considered in all fire management programs. Although wood smoke does not contain significant levels of environmentally dangerous pollutants, it can be aesthetically disturbing (Hall 1972). For this reason it is often advisable that burning be carried out during periods when wind will carry smoke away from populated areas. Smoke can often be minimized by burning at temperatures hot enough that near complete combustion occurs. It should, of course, also be emphasized that the smoke produced by prescribed burns may be slight compared to that which would result from the usually inevitable uncontrolled wildfire. In addition, recent studies suggest that wood smoke from natural or prescribed fires may have beneficial effects on microbial activity including the control of certain pathogenic fungi and other disease organisms (Parmeter and Uhrenholdt 1974).

INTEGRATED FIRE MANAGEMENT - AN EXAMPLE FROM SEQUOIA AND KINGS CANYON NATIONAL PARKS

Sequoia and Kings Canyon National Parks, located in the southern Sierra Nevada of California, have had an integrated fire management program since 1968. This program combines fire suppression, prescribed burning and natural fire in an effort to achieve the ultimate objective of restoring fire to its natural role in all Park communities. Along with a similar program in Yosemite National Park this represents one of only a few cases where fire is used as a management tool for the expressed purpose of preserving naturally functioning ecosystems.

The long term impacts of the fire suppression policy which had been in effect in these Parks since about 1900 (Vankat 1977) first received widespread coverage with the publication of the Leopold Report in 1963. Primary concern was focused on the fire danger resulting from heavy ground fuel buildups and dense reproduction of white fir (Abies concolor) within the groves of giant sequoia (Sequoiadendron giganteum). There was also concern over the apparent lack of giant sequoia reproduction. Subsequent studies have confirmed these concerns. The increase in white fir, as well as altering successional patterns, has increased the chances of destructive crown fires (Kilgore and Sando 1975). Meanwhile, Hartesveldt et al. (1975) have clearly documented the need for periodic fire for successful sequoia reproduction. This type of information, together with a growing interest in understanding the natural role of fire in other Park ecosystems (Kilgore 1973b, Parsons 1976) has provided much of the justification needed to develop a fire management program based on the need to re-establish fire to its natural role throughout the Parks.

Ranging in elevation from about 400 to over 4,400 meters, Sequoia and Kings Canyon National Parks contain most of the typical California "fire-type" communities. These range from the low elevation chaparral and oak woodland through the middle elevation mixed conifer forest types, including the giant sequoia groves, to the higher elevation lodgepole pine (Pinus contorta var. murrayana) and subalpine forests.

In order to implement an effective fire management program we need to understand the natural role of fire in each community type, including, where possible, natural fire frequencies and intensities. Basic vegetation and fuels sampling was necessary to understand existing vegetative mosaics and fuel buildups. Climatic and topographic variations needed to be studied and their potential effects on burning patterns evaluated. Finally, the effects of varying fire prescriptions (ranges of fuel moisture, air temperature, relative humidity and wind speed) and fire types (back fire versus head fire) needed to be established for each vegetation type. Such information, the collection of which continues, provides a basis for predicting fire intensities as well as for evaluating the short and long term effectiveness of individual management burns.

The Program

The fire management program of Sequoia and Kings Canyon National Parks consists of a three phased approach. In the higher elevations, where fuel accumulations are low and growth rates slow, naturally ignited fires are allowed to run their course. In the middle elevation sequoia-mixed conifer forest zone prescribed burning is used in an effort to reduce existing fuel accumulations to a point where natural fires can again be allowed to burn. Naturally ignited or man-caused fires which occur in this zone but do not fall within predetermined block boundaries and prescriptions are suppressed. Immediate suppression action is also taken on all low elevation fires and in and around developed areas. Research and monitoring activities are ongoing in all three zones in an effort to better understand the effects of fire on different Park communities as well as to provide a basis for refining and expanding the natural and prescribed fire programs.

Natural Fire

The high elevation lodgepole pine and subalpine forest communities of the Parks are characterized by long lived, widely spaced, and relatively short statured trees (Rundel et al. 1977). These forests are thought to have evolved with infrequent low intensity ground fires (Vankat 1970). Since temperatures remain low and the growing season is short the years since fire suppression became effective have not yet resulted in excessive fuel accumulations in these areas. For this reason most of these higher elevation forest communities have been included in a Natural Fire Management Zone. This Zone, which now includes over 71 percent of the Parks 342,898 hectares, is generally located above 2400 m. Fuel type, topography, exposure and zone configuration all have been considered

Table 1--Number of lightning fires, by size class, in the high elevation Natural Fire Management Zone, Sequoia and Kings Canyon National Parks.

Year	Size Class (hectares)					Total hectares
	0-0.1	0.1-3.9	4-39	40-120	121+	
1968	1	1	0	0	0	3.2
1969	2	0	0	0	0	0.1
1970	20	1	2	0	1	200.0
1971	18	0	0	1	0	57.3
1972	11	2	2	1	0	65.5
1973	7	1	0	0	3	1,932.2
1974	15	0	2	1	1	1,340.8
1975	4	1	2	0	0	23.6
1976	14	5	1	0	0	31.3
Total	92	11	9	3	5	3,654.0

in setting the Zone boundaries (Kilgore and Briggs 1972).

Within the Natural Fire Management Zone all naturally ignited (lightning) fires are allowed to burn. All such fires are continually monitored by air, and whenever feasible by ground reconnaissance. Suppression action is taken only if the fire threatens to escape Zone boundaries or poses a threat to structures or public safety. News releases, signs, brochures and interpretive talks have been successfully used to educate the public about the program.

In the nine years since the natural fire program was instituted 120 fires have burned a total of 3,654 ha (table 1). Seventy-five percent of the fires have remained under 0.1 ha in size while three have been over 700 ha. The largest burned a total of 1,239 ha. The fires have generally been slow burning, low intensity ground fires (fig. 1) which only occasionally get into the tree canopy. Characteristically these fires pick up in intensity during the warm afternoons and die down at night. They commonly travel slowly through duff or along downed trees from one clump of standing vegetation to another. Rock outcrops, ridge tops and other areas of sparse vegetation provide numerous natural breaks which slow the fire's progress. The larger of these slow burning fires have continued to burn for periods of two or three months before being extinguished by winter snows. Finally, while a precise economic analysis of the program is difficult to make it is obvious that substantial savings have been made by not having to suppress these fires.

Research and monitoring activities carried out to date have centered in the Roaring River drainage of Kings Canyon National Park. Characterized by an overstory of lodgepole pine, white fir and Jeffrey pine (*Pinus jeffreyi*) and an understory of green leaf manzanita (*Arctostaphylos patula*) this basin ranges in elevation from about 2100 m to 2800 m. Three of the four largest natural fires recorded to date have been in this area. Still another fire, which threatens to be the largest yet was actively burning in this area as of August 1, 1977. Studies conducted on the effects of two of these fires on downstream water quality (Hoffman and Ferreira 1976)

Figure 1--Slow burning high elevation lightning caused fire in Kings Canyon National Park, California.

showed only minor changes in various physical, chemical and biological parameters. Research

Table 2--Accumulation of downed woody material, in kilograms per hectare, following different periods since burning.

Size-Class	Time Since Fire				
	Unburned 1/	Immediate Post-Burn	1 Year	4 Years	7 Years
0-0.64cm	578	229	261	1,131	908
0.64-2.54cm	4,208	580	854	3,086	3,965
2.54-7.62cm	6,834	1,070	1,427	2,646	5,222
over 7.62cm	114,018	13,735	14,522	20,659	54,806

1/ Unburned for over 50 years; exact date of last burn unknown.

on the impact of the fires on vegetation structure and succession and wildlife use patterns is still being carried out. In the future as many of the larger high elevation natural burns as possible will be routinely monitored for weather, fuel, vegetation and fire behavior conditions. This data will provide a basis from which to predict the behavior and impact of future natural fires.

Prescribed Burning

The middle elevation mixed conifer forest zone was the area for which concern was first expressed about the impact of the Parks fire-suppression policy. The buildup of flammable ground fuels, the increase of white fir and the lack of giant sequoia reproduction all pointed towards the need to reintroduce fire into this zone. The problem was that due to the fuel buildup, which had accumulated during the previous 75 years it was impossible to simulate the frequent, low intensity ground fires which were common before the coming of European man. It was obvious that some sort of carefully controlled fire management program would be necessary.

Following a number of experiment burns, including several by Dr. Harold Biswell on nearby University of California property, a prescribed burning program was instituted in the Redwood Mountain grove of giant sequoias in Kings Canyon National Park in 1969. While the ultimate objective of the program was to restore fire to its natural role the immediate goal of individual prescribed burns was to eliminate the buildup of ground fuels as well as reduce the density of young white fir which were filling in the once open forest floor. Since the inception of the program something over 400 ha have been prescription burned in the sequoia-mixed conifer forest type. Burn preparation consists of line construction around predetermined blocks and the falling of an occasional snag. No other vegetation manipulation is needed. Burning has usually been conducted in the fall under carefully prescribed conditions of temperature, relative humidity, fuel moisture and wind speed and direction. It is this combination of environmental conditions, or "prescription," together with the type of fire that determines the intensity of any given burn. Fires which start under dry summer conditions are still suppressed in this zone.

Basic studies on the fire ecology, vegetation structure, composition and age distribution of the sequoia-mixed conifer forests of the Parks have provided valuable information on which to build an effective fire management program (Bonnickson 1975, Hartesveldt et al. 1975). Studies are also underway to better understand past vegetation structure, thus providing a baseline against which to evaluate the effectiveness of future burns in restoring pristine conditions. Before and after each prescribed burn studies are made on the effects of the fire on vegetation structure and fuel consumption. For example, Kilgore (1973b) has documented that up to 87 percent of the saplings and 38 percent of the trees (mainly white fir) between 15 and 30 cm in diameter were killed and the majority of the ground fuels consumed by a relatively light surface burn. Table 2 summarizes recently collected data on the buildup of downed woody fuels following different periods since burning. The data shows that except for in the largest size class, the accumulation approaches unburned levels within about seven years following prescribed burning. The fact that the natural fire frequency is known to have been much more often than the 50 to 75 years experienced here indicates that the unburned fuel levels must have been considerably higher than those commonly found under a more natural fire regime. Thus, the fuel levels found here after only seven years may well be within the range that they normally would have been before being naturally reburned.

In order to fully simulate natural conditions we need to know what the fire frequency

of the area was before the coming of European man. Tree ring and fire scar studies in the mixed conifer forests of the southern Sierra Nevada show average minimum natural fire frequencies to be in the neighborhood of seven to nine years (Kilgore 1973a). Frequencies for any given area vary as a function of slope, elevation and forest type. Kilgore and Taylor (pers. communication) have recently documented mean intervals between fires for given sites in and around Kings Canyon ranging from 5.5 years in a ponderosa pine (Pinus ponderosa) type to between 15 and 18 years in the more mesic white fir forest. The fires were generally low intensity ground fires which occurred frequently enough that hazardous fuel buildups were seldom attained. Most of these fires apparently remained relatively small in size (less than 16 ha), with only occasional large fires burning 100 ha or more. This type of information is significant in that it provides a baseline against which we can compare the frequency, size, and intensity of future prescribed and natural fires.

Other studies which have helped us to better understand the ecological role of fire, and thus to evaluate our fire management program, in these mixed conifer forest types have included documentation of the effectiveness of fire in stimulating sequoia reproduction and survival as well as the effects of prescribed burning on bird and mammal populations (Harvey et al. 1978). In addition, St. John and Rundel (1976) have documented the effectiveness of the burning program in mineralizing forest floor organic matter while Kilgore and Sando (1975) have shown how the program effectively reduces the potential for hazardous crown fires.

Despite the numerous studies which have been conducted in conjunction with the Parks prescribed burning program additional documentation is needed. In order to understand the effects of varying prescriptions on fuel consumption, vegetation kill and fire intensity, experimental burns with detailed measurements of fuel loading, rate of spread and other behavioral characteristics are needed (Van Wagtendonk 1974). These should be conducted under varying prescriptions and at different times of the year. Other areas which need attention include the impact of smoke on disease organisms, and the effects of prescribed burning on such things as large mammals, water quality and runoff. A better understanding of public awareness of and willingness to accept the program is also needed.

Finally, it is important to understand that the task ahead is a large one and that if we hope to expand the program throughout the entire mixed conifer zone it will be necessary to work out ways of burning considerably larger units. Furthermore, each area which is prescribed burned will probably have to be reburned several times before the accumulated fuel hazards are reduced to the point where consideration can be given to allowing natural fires to burn.

Fire Suppression

The lower elevations of the Parks (below about 1800 m) are characterized by chaparral brushlands and open oak woodlands. Although it is known that fire has played a vital role in the evolution of these community types the potential fire hazards are considered so high that no prescribed burning has yet been attempted (Parsons 1976). Ongoing management oriented research is aimed at documenting the effects of long term fire suppression as well as finding acceptable ways to reduce the unnatural fuel accumulations and to re-establish fire in its natural role. Once basic information on vegetation structure and succession, fuel loading and moisture variation, and microclimatic patterns is collected small-scale experimental burns will be carried out in an effort to develop acceptable burning prescriptions. Intensive monitoring will be conducted on all experimental burns and wildfires in order to better understand the effects of different fire intensities.

In the meantime all fires, natural or man caused, occurring in the chaparral - oak woodland zone are immediately suppressed. This helps to minimize the chances of an uncontrollable wildfire sweeping upslope into the vulnerable giant sequoia groves.

The Future

In order to fully restore fire to its natural role in all Park ecosystems, it will be necessary to expand the ongoing prescribed burning program to include all of the middle and lower elevation forest and brushland communities. In addition, considerably larger acreages will need to be burned each year. This will require the collection of extensive baseline data on past fire frequencies as well as present vegetation structure, fuel loading and climatic variation. An accelerated program of experimental burns and sophisticated monitoring and research is badly needed for most all of the Parks community types. As such information is obtained it should be incorporated into a computer based resource information

system which can retrieve the basic data and integrate it with available fire models (Rothermel 1972). This will allow prediction of real-time fire behavior as well as post-burn succession for fires under given environmental conditions (Kessell 1976). We believe that such a progressive, scientifically based, expanded fire management program is essential to the preservation of naturally functioning Park ecosystems.

SUMMARY

Most of the world's "fire-type" ecosystems have been subjected to varying degrees of fire suppression over the past several centuries. The result has been a change in successional patterns which in some cases threatens the very existence of whole communities. In national parks and other wilderness areas where the management objective is to preserve naturally functioning ecosystems it is important that man's activities not be allowed to interrupt these natural processes.

In the Mediterranean climate areas of the world fire has probably been the most important factor in the evolution of the typical Mediterranean scrub and forest vegetations. While fire has been used as a management tool in many of these areas the concept of using it for the purpose of preservation is relatively new. Yet if examples of naturally functioning ecosystems are going to be maintained in these areas it is essential that fire be allowed to again play its natural role.

Sequoia and Kings Canyon National Parks represent an example of an area which has an active program of using fire for the purposes of preserving its native ecosystems. These Parks have combined research efforts with management action to develop an effective program of re-introducing fire as a natural process. While the total program is still a long way from fully accomplishing its objective, the concept of using fire as a tool for preservation provides a conceptually sound basis from which to work.

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EFFECTS OF FIRE ON WILDLIFE COMMUNITIES[1]

Hartmut Walter[2]

Abstract: Human manipulation of the fire factor has altered the indirect effects of fire on wildlife communities. The consequences of the "suppression" and the "ecological" fire philosophies as well as the response of landscapes and their wildlife are discussed. Models and methodologies are developed for the quantitative and comparative analysis of the effects of fire on wildlife. Case studies and examples from Sardinia and other regions in the Mediterranean are presented illustrating the effects of fire on bird species and regional bird communities.

Key words: Fire philosophies, effects of fire suppression, fire tolerance model, fire dependence of Sylvia warblers, Tyrrhenian islands.

INTRODUCTION

The effects of fire on wildlife are of interest for several reasons: (1) the basic research regarding the physiological and behavioral adaptations to fire among different organisms has only begun; (2) the policy of fire suppression is increasingly being blamed for interfering with the normal ecological dynamics of many ecosystems on earth; (3) the historic and current impact of human-generated fires on ecosystems and their wildlife is not well understood at present; and (4) there is an urgent need to evaluate the role of fire in the conservation of game species, of rare and endangered species, and of wildlife communities confined to parks and "natural" reserves.

This paper focuses on the indirect effects of fire on wildlife populations and communities. It stresses the implications of contrasting human attitudes and policies toward fire for the dynamics, structure and function of animal communities. An attempt is made to discern the key components of the fire factor and to develop a conceptual framework and methodology for the quantitative and comparative analysis of fire-related effects on wildlife.

[1] Presented at the Symposium on Environmental Consequences of Fire and Fuel Management in Mediterranean Ecosystems, Palo Alto, California, Aug. 1-5, 1977.

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HUMAN ATTITUDES ON FIRE: IMPLICATIONS FOR WILDLIFE

The direct effects of fire on wildlife have not aroused much interest because most animals escape any adverse impact from heat, smoke, desiccation, etc. They move away from the fire front or stay in fire-resistant microenvironments. Komarek (1969) and Bendell (1974) have reviewed the often rather anecdotal and qualitative literature regarding the physiological and behavioral response of animals to fire. In general, the implications of direct fire effects may be severe for individual organisms but slight to negligible for wildlife populations and communities.

The indirect effects of fire, however, are of the greatest importance for wildlife. They are mostly the result of significant habitat changes caused by fire. Other environmental factors may also develop a new momentum in the wake of a fire creating synergistic effects of an indirect but potent nature on wildlife. Such factors are soil erosion, interspecific competition, human land use after the fire, etc. These indirect effects have been perceived in the literature, (Kozlowski and Ahlgren, 1974) but more research needs to be done in order to fully understand their magnitude. The increasing role of man in the management of fire-prone environments has complicated this task. On the one hand, millions of dollars are spent to suppress fire in often tinder-dry chaparral and forest areas where fire ecologists perceive the fire factor as an active and necessary agent of the normal

environmental dynamics (Biswell 1963 and 1974, Komarek 1966 and 1968, Parsons 1976). On the other hand, entire landscapes in southern Europe and in North Africa may owe their evolution to the excessive frequency of fire brought about by thousands of years of human interference in natural ecological cycles.

In North America, at least, the "suppression" philosophy is beginning to be modified or even replaced by an "ecological" fire philosophy. If translated into new attitudes and management policies, this shift could strongly affect wildlife habitats. The artificiality of many of today's shrublands and forests in western North America--a result of the "suppression" philosophy--and their respective, equally artificial (or anthropogenous) wildlife communities would gradually disappear.

Ideally, a fire policy based on the "ecological" philosophy would lead to the evolution of wildlife communities adapted to fire where this factor is a frequent agent of ecological change or turnover. Fire control efforts would be confined to a minimum in such areas; they would be increased in regions where fire is extremely rare and accidental in order to prevent long term damage to poorly adapted ecosystems (fig. 1). In practice, American

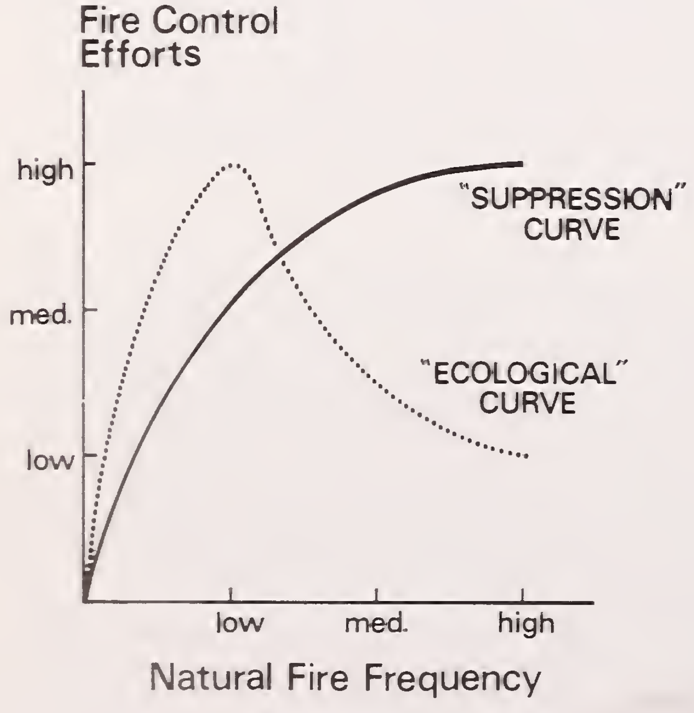

Figure 1--Illustration of the contrast between two fire philosophies.

and Mediterranean environments will probably not return to their pre-"suppression" state. California's landscapes will be a lasting testimony of the "suppression" philosophy: everywhere are pine and eucalyptus plantations that would never survive a natural fire, and California's urban and recreational areas have spread far into fire-prone chaparral and forest lands. The public will not accept fire as a normal and positive ecological agent as long as zoning ordinances, building codes and forestry practices make it mandatory to fight fires in order to protect human lives and property. At best, we can hope to return the fire factor to uninhabited foothill and mountain territory. Prescribed burning techniques have been successfully used in many environments to speed up the return of fire-adapted habitats and to optimize their resource value for wildlife species (State of California 1963, Hendricks 1968, Dasmann et. al. 1968).

In southern Europe, where the meteorological conditions are very different from those in western North America (Komarek 1966 and 1968, Susmel 1974) human-generated fires have been used for centuries as a land management device. Most of Italy and the Tyrrhenian islands were covered by forests before 5,000 B.C. The synergistic effects of high population density, industrial demand for wood, grazing and browsing of livestock, and frequent fires have replaced most forests with the well known Mediterranean garrigue and maquis. The shift to non-forest habitats has had a profound effect on the composition of the wildlife community. Detailed studies on this topic do not seem to exist. As the Mediterranean countries become more interested in their natural heritage they will have to assess the effects of excess fires and to carefully evaluate the potential role of natural or prescribed fires in wildlife management.

More efforts should also be made to analyze the indirect effects of fire policies (prescribed burning, "natural" fires) adopted for the management of multiple use areas (parks, national forests in the U.S.). Such policies are rarely specifically designed for wildlife management. Park and forest managers usually give higher priority to water, soil, timber, and recreation factors. We must ask what effects of those fire policies will be felt by (1) local game species and (2) rare and endangered species in the short and long term.

Where reserves have been developed to preserve an endangered species (Cowles 1968) or entire ecosystems ("biosphere reserves"), an evaluation of the fire factor would appear to be of crucial importance.

Any research on the fire-wildlife relationship -- whether it concerns direct or indirect effects, single species or communities -- will center on the question: How fire-adapted or fire-dependent is the species or the community? In the following an attempt is made to provide a general conceptual framework for a more quantitatively and comparatively oriented analysis of the fire-wildlife relationship.

A FIRE TOLERANCE MODEL FOR WILDLIFE

Fires can be described and analyzed by monitoring their physical and chemical characters. These include temperature, oxygen, fuel, wind speed, height of the flame, spread rate of the fire front, etc. (Byram 1959, Trabaud 1976).

Only a few of these characters need to be known in order to measure the short and long term impact of a fire on a wildlife population. My experience with vertebrate populations in fire-prone environments leads me to suggest that three components of the fire complex can be singled out as determinants of the survival of a wildlife population. They are fire frequency (F), fire intensity (I) and fire area/terrain (A). These three components are interdependent and can be understood as gradients along the x, y, and z axis in three-dimensional space (fig. 2).

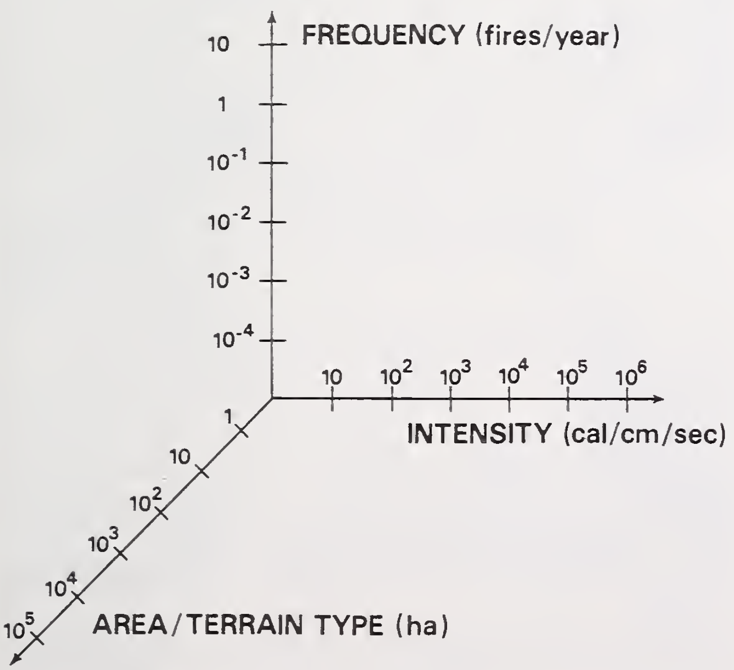

Figure 2--Gradients of three major limiting factors of the fire tolerance of wildlife populations and communities.

The frequency gradient (F) relates the frequency of fires in a given location or area. The scale ranges from an extremely low frequency (less than one fire in 10,000 years) to a maximum frequency of 10 fires per year. It is evident that fire frequency is a determinant since it regulates the period available for vegetation growth and other successional or cyclical phenomena within many ecosystems on earth.

The intensity gradient (I) is a function of three important fire variables (adapted from Byram 1959, p. 79):

$$I = cmr \qquad (1)$$

where I = fire intensity in calories per gram of fuel per second
c = heat yield in calories per gram of fuel
m = mass of available (or effectively burned) fuel in grams per cm^2
r = rate of spread of the fire front in centimeters per second

The intensity of fires can vary greatly. In a recent experiment Trabaud (pers. commun.) found an I value of 3,494 cal/cm/sec in a maquis fire near Montpellier that advanced at a speed of 6 cm/sec. In general, values of I may vary from 40 to over 250,000 cal/cm/sec.

The fire tolerance (T_1) of a population p_1 within a given area is a function of F_1 and I_1:

$$T_1 = f\,(F_1, I_1) \qquad (2)$$

The populations of other species within the same area may have different fire tolerances (T_2, T_3, ...T_n). The tolerance (T) of the entire community can then be expressed as

$$T = \quad f\,(F, I) \qquad (3)$$

Figure 3 shows one of the possible curves of the T_1 or T functions. In order to provide more detail the area under the curve indicates also under which conditions of F and I over 90%, 50% and 10% of a population or of the total number of species will tolerate (survive) the fire factor.

If we want to compare populations and communities of similar size between different locations or regions we have to add an important, often overlooked factor expressing the size of the fire and the terrain complexity of this area. The relevance of the area/terrain type gradient (A) is particularly evident to biogeographers in southern California. Rugged terrain strongly affects the behavior of chaparral fires. Stands of oak and other trees develop and maintain themselves

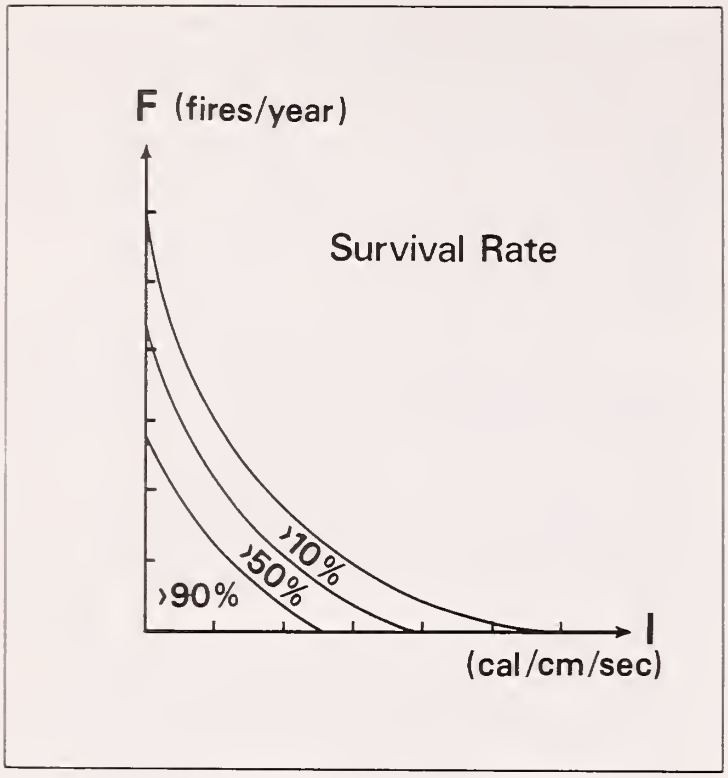

Figure 3--Percentage of the total number of individuals or species surviving different fire impact levels.

in depressions, along valley bottoms, and in other places that are not affected by most fire events (fig. 4).

There is an inverse relationship between terrain complexity and the survival of animal habitats. The more complex the terrain is the less pronounced will be the effect of fire on wildlife, everything else being equal. The fire area itself is an important factor since it is related to population size, dispersion and habitat diversity. The larger the fire area is the greater will generally be the fire's effects on wildlife. In order to combine the area with the terrain factor we divide the fire area by the terrain type. There are six terrain types:

Type 1--extremely dissected, rugged mountainous
Type 2--very rugged, highly uneven
Type 3--steep slopes, irregular
Type 4--undulating hills
Type 5--gentle slopes
Type 6--level

Examples for the A gradient: Fire has burned over 3,000 ha in terrain type 3. The value entered for A is 1,000 (ha). Had the same fire burned over 3,000 ha in terrain type 5, the A value would be 600 (ha) instead. This means that the area-related tolerance limits of wildlife populations are lower for the latter than for the former fire.

We can now attempt to develop a fire tolerance model. The effects of fire on wildlife are a function of the three gradients F, I, and A:

$$T = f(F, I, A) \qquad (4)$$

The position or tolerance limits of a population can be indicated in the three-dimensional graph (fig. 2) as the volume within which at least some part of the population will survive the fire-related effects.

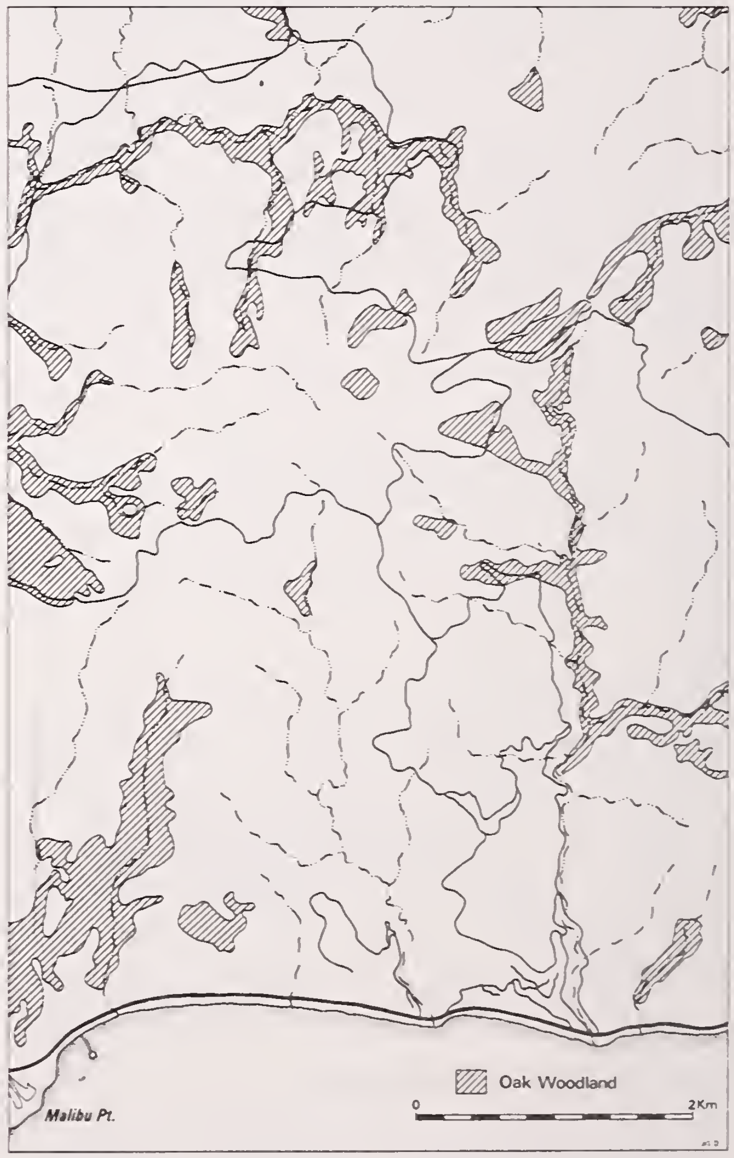

Figure 4--Fire-generated (pyrogenous) habitat mosaic of coastal sage brush and oak groves along the Malibu Coast (California).

Figure 5 depicts four characteristic tolerance configurations. Two extreme examples are shown: a population that is extremely sensitive to fire-related phenomena and therefore termed "fire-intolerant" (1), and a population that is not affected by any kind of fire, termed "fire-impervious" (2). Most wildlife populations, however, appear to be "fire-adapted" (3), i.e. they can tolerate fire up to a certain critical threshold. The extreme case of adaptation is reached where a species cannot survive in a given environment unless this environment is subjected to a frequent and strong fire "pulse". This is the "fire-dependent" (4) population.

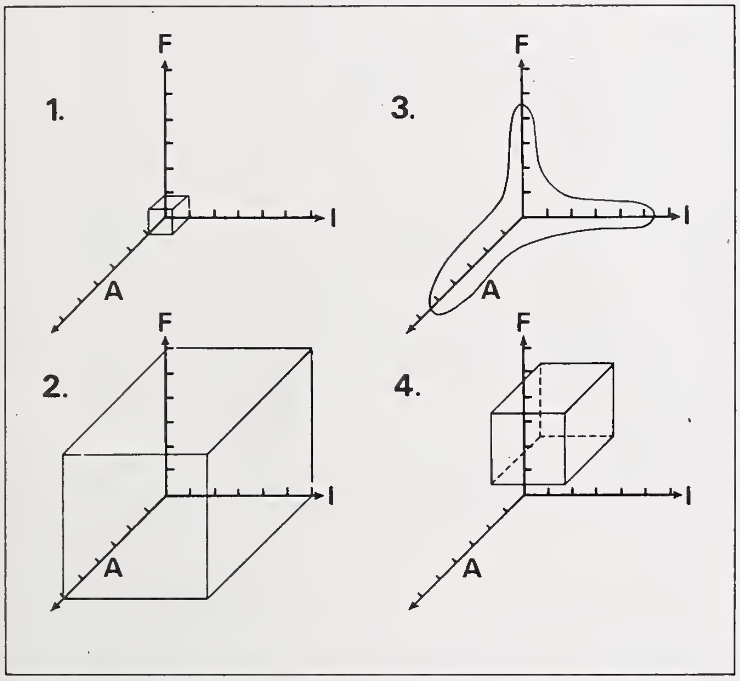

Figure 5--Tolerance "volumes" of wildlife populations. Population is (1) fire-intolerant, (2) fire-impervious, (3) fire-adapted, and (4) fire-dependent.

Some time will probably elapse before somebody succeeds in measuring the actual T values of an animal population. Even without quantifiable data, however, models such as this one can serve the needs of ecologists, wildlife managers and biogeographers. As long as we have some data indicating the relative position of different populations along the three gradients F, I, and A, we can determine their relative survival rates after fire, i.e. their relative tolerance limits to different types of fire.

GEOGRAPHIC ASPECTS OF FIRE'S EFFECTS ON WILDLIFE

It is not difficult to outline some aspects of the population geography after the fire event. Depending on the tolerance function T of a population it will disappear, become less or more numerous or remain unchanged in population size.

Very common in California's chaparral habitat is the temporary "thinning out" phenomenon of small rodents and bird species after fire (Lawrence 1966). This is either a result of high mortality, of an out-migration or of both factors. Dispersal from burned over areas to unburned habitat pockets appears to be frequent wherever such "refuges" exist (see fig. 4). This creates, at least for a number of years, a cluster-type dispersion pattern. Gradually, as the brushlands grow back to their former heights and density, individuals from the cluster area will recolonize the pre-fire distribution area.

The existence of habitat mosaics within and around fire areas appears to be particularly important for resource and habitat specialists. Even if they are fire-dependent they may still lose their resources and/or habitats after a fire and are then in need of suitable ecological space. Generalist-type species, on the other hand, should be less affected by fire events because of their large ecological valency (Bendell 1974). We should therefore expect to find more generalists than specialists in fire-prone environments, particularly those where the terrain is simple (type 4-6) and does not favor the development of burned and unburned habitat mosaics.

FIRE AND THE MEDITERRANEAN BIRD COMMUNITIES

As an ornithologist and biogeographer I have been interested in the interaction between man, habitats and birds for many years. Many "fire vegetation types" in the Mediterranean have replaced most of the "original, pristine forests that apparently once covered the fertile lowlands" (Naveh 1974). Numerous variants of degraded and regenerating vegetation types exist. Birds occur in all these habitats, from the coast to the highest mountains and from the pristine remnant to the extreme state of degradation and ecological "abuse".

Pending further investigation of the role of fire on Mediterranean vertebrates it seems worthwhile in the context of this paper to at least describe the magnitude of the indirect

effects of fire-associated human impact on the bird community. We know little about the distribution of bird species prior to the onset of the destructive pastoral burning practice of the middle ages. It is reasonable to assume that a small percentage of the current bird fauna did not exist there some 1,000 or 4,000 years ago. It is equally reasonable to expect a historic presence of a small number of species in various regions of the Mediterranean where they are completely absent today. Most of today's species, however, have probably existed in this area for several thousands of years. It is best, therefore, to compile a list of today's breeding birds and compare their habitat preferences and foraging strategies with the resources being offered by the Mediterranean landscape. Which bird species were most likely to be adversely affected by the landscape transformation from mature, perhaps open (fire-adapted) forests to the variety of today's maquis, garrigue and agricultural habitats? The typical forest species have certainly decreased in distribution area and population size.

How many bird species have benefited from this landscape transformation, and how many have remained unaffected? Table 1 summarizes such data for the Italian mainland, the three largest islands surrounding the Tyrrhenian Sea and the large Maghreb region of NW Africa. Predictably, the smallest area (Corsica) has the lowest number of breeding bird species (summer visitors and year-round residents, compiled from various authors and my own field data). A high 29% of its bird community is likely to decrease in numbers as a result of human-caused burning efforts. The same percentage (35 species) would, however, increase in numbers. Only 42% would not be affected (some raptors, coastal and water birds, high mountain species). A high percentage of desert birds in the Maghreb's avifauna contributes to a relatively low impact of fire-related events in this region. In the other areas, however, between 55-58% of today's avifauna has probably been positively or negatively affected by the historical vegetation transformation. Thus, the fire factor has undoubtedly strongly contributed to the composition of the present avifaunas in the western Mediterranean.

FIRE-DEPENDENT SYLVIA WARBLERS OF SARDINIA

Among the bird species that have benefited from the historic change of the Mediterranean landscape are several southern European representatives of the genus *Sylvia*. These are small, rather inconspicuous and secretive warblers, in appearance much like the well known wrentit (*Chamaea fasciata*) of California's chaparral country. The distribution and density of *Sylvia* warblers is closely correlated with man's effects on the landscape, particularly with the nature of the fire cycle. In the following I will attempt to illuminate the indicator role of the genus *Sylvia* with respect to fire from three different angles. To my knowledge, no other closely related taxonomic group in the convergent habitats of South Africa, Chile and California (Cody 1975, Thrower and Bradbury 1977) "responds" in such species specific ways to even seemingly minute habitat differences caused primarily by fire.

Five species of the genus *Sylvia* occur within the 1-5 m tall macchia stands that cover much of the island of Sardinia (total surface area around 24,000 Km^2). Their niche breadth, territoriality and interspecific competition have been studied over habitat gradients ranging from dwarf macchia and

Table 1--Indirect effects of fire on the abundance and distribution of breeding birds.

Area	Total # species	# Species decreasing (%)		# Species increasing (%)		# Species not affected (%)	
Maghreb	242	44	(18)	50	(21)	148	(61)
Italy	211	61	(29)	51	(24)	99	(47)
Sicily	138	39	(28)	37	(27)	62	(45)
Sardinia	126	29	(23)	38	(30)	59	(47)
Corsica	121	35	(29)	35	(29)	51	(42)

grassland to oak woodland and coniferous forests (Cody and Walter 1976). Their spatial and seasonal occurrence has also been analyzed (Walter, in prepar.). For the purposes of the present analysis it is sufficient to only briefly characterize each *Sylvia* species.

S. sarda: Occurs only in short, often degraded or nutritionally poor habitats (low macchia) with at least some rocky substrate. Known to forage on the ground. Poorly adapted for competition in richer, more complex habitats.

S. undata: Sympatric sibling species of *S. sarda*. Rarely in the same micro-habitat as the latter species. Prefers dense, homogeneous macchia of 1-3 in in height. A habitat specialist.

S. melanocephala: The ecological generalist in this group. Prefers heterogeneous habitats with diversity in terms of vegetation height and density. Occurs also in orchards and agricultural areas.

S. cantillans: In open forest or in medium to tall macchia with interspersed trees or tall shrubs.

S. atricapilla: In tall stands of macchia, and in coniferous and broad-leafed woodlands.

The composition and the morphology of Sardinian macchia correlates well with different fire regimes. It is not difficult at all to judge the date of the last fire from the characters found in a macchia stand. In addition, forestry records are available in many areas. After a fire, the Sardinian macchia of the foothills and lower mountains follows a typical successional sequence, beginning with pioneer shrubs like *Cistus monspeliensis* followed by resprouting shrubs like *Arbutus unedo* and *Erica arborea*. A high fire frequency gradually impoverishes the soil leading to quasi-permanent low *Cistus* macchias. Prolonged intervals between fires, on the other hand, lead to the formation of very tall macchia containing substantial numbers of oaks or oak-like species. In summary, the nature of the fire regime determines the height, composition, and quality of macchia habitats.

Since each of the five *Sylvia* species occupies a different range of macchia habitats, each of them is affected indirectly by the fire regime in a different way. This can easily be demonstrated by monitoring *Sylvia* density and diversity within the same habitat and between habitats over time (Cody and Walter 1976). If we relate these biological data to the fire history of the *Sylvia* habitats we can determine the fire tolerance of each species.

In figure 6 a model habitat of about 40 ha size has been subdivided into four habitat patches. Every six years a fire destroys one of the four patches. In this hypothetical example, the fire event sweeps always through the oldest, i.e. the 24-year old, rather tall macchia habitat. Such a fire regime permits all five *Sylvia* species to persist in the 40 ha area. Each species has to move from one patch to another one, however, because none of the five species occur in each of the successional habitats.

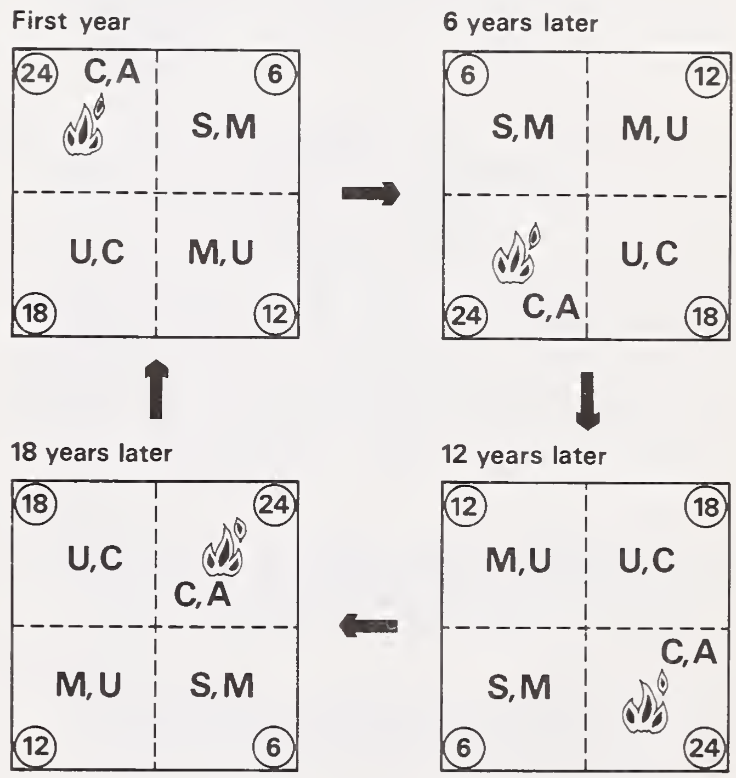

Figure 6--Model of the cyclical geography of five *Sylvia* warbler species.

S. sarda (S) can occupy only the habitat patch that had a fire event within the last six years. Older patches are occupied by *S. undata* (U), *S. cantillans* (C), and finally *S. atricapilla* (A). The latter can only occupy the 18-24 year old macchia because of its preference for arboreal vegetation. *S. melanocephala* (M) and *S. cantillans* (C) occur in two patches at a time. The former might even occur in all four patches if the older stands offered a considerable degree of heterogeneity. After 24 years the total area has gone through one complete fire-regulated cycle. The *Sylvia* community has also completed a full cycle of rearranging their geography and population density within the area.

In reality, this simplified situation will only rarely occur. Firstly, some habitats experience a rather slow progression of the

vegetational succession. This prolongs the time period available to the early succession species, i.e. S. sarda (S) and S. melanocephala (M). Secondly, fire frequencies vary greatly. There are many areas in Sardinia that have been burned over every three to five years. This would again favor the species S and M of our model and exclude the other three species from the area. Thirdly, frequent cutting of brush and wood and the regular grazing and browsing by sheep and goats may modify the structure of the macchia habitats. The Sylvia community will respond in characteristic ways to such variable impacts on the Mediterranean vegetation.

In figure 7, six types of impact have been correlated with the Sylvia community structure and dynamics: Type I has had only one fire within the study period of 90 years. The macchia quickly reverts back to an elfin-type forest. Type II is similar to type I but regular cutting of wood creates clearings and low brush areas within the elfin forest. This creates suitable habitats for up to four Sylvia species compared to only one (A) in the undisturbed elfin forest. Type III experiences fire every 30 years, Type IV has a 15-year fire cycle, and Type V has a 6-9 year fire cycle. In the Type VI model, fires occur every 6-9 years, and the area is heavily utilized by pastoral grazing and browsing. As fire frequency increases, species A and C disappear. In the Type VI habitat only S. sarda (S) and S. melanocephala (M) persist.

The great dependence of the Sylvia species on habitat height and structure (cover, density) which, in turn, reflect the nature of an area's fire regime can also be used for an estimate of each species' fire tolerance (fig. 8). If we want to assess the combined indirect effects of fire frequency (F) and fire intensity (I) within the same area/terrain type environment, then we have only to consider the F and T gradients of the fire tolerance model (fig. 2). The evaluation of the habitat data of the Sardinian Sylvia community (Walter, in prepar.) and their interspecific competition (Cody and Walter 1976) provides sufficient information for at least a rough and relative model of the total community tolerance (T). It is the sum of the data points along both gradients that fall within the fire tolerance limits of each species' population. Sylvia sarda and S. undata are fire-dependent species. S. melanocephala and S. cantillans are fire-adapted but not fire-dependent while S. atricapilla is rather fire-intolerant. This latter species has certainly been curtailed in its distribution and

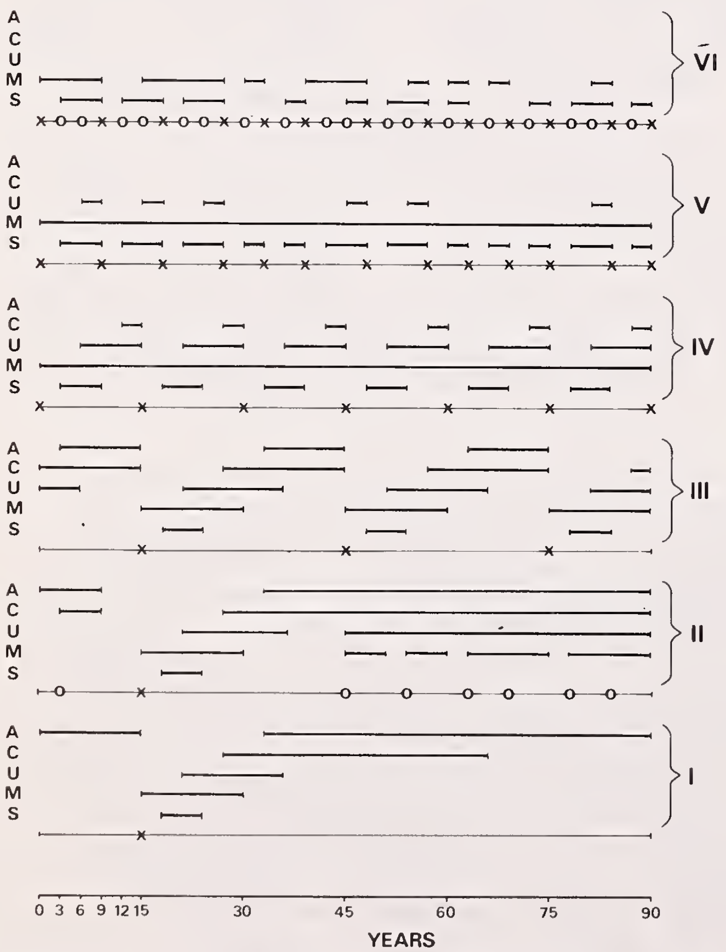

Figure 7--Sylvia warbler community structure and temporal dynamics in response to fire (x) and human habitat use (o).

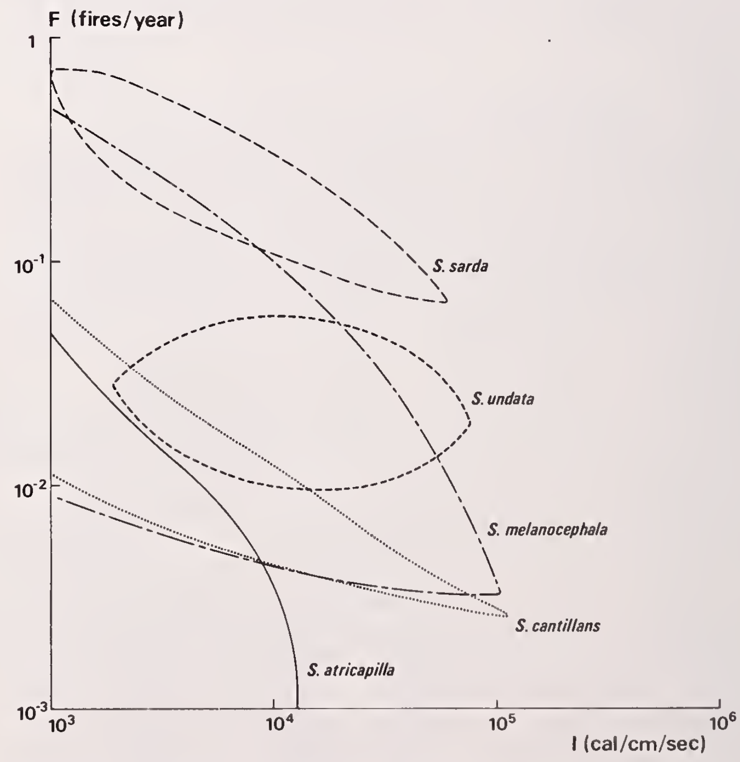

Figure 8--Fire tolerance model of the Sylvia warbler community in Sardinia.

population size as a result of the historic human impact on Sardinia's landscape. The other four species, however, have substantially or greatly benefited from this impact, primarily because of the effects of fire on Mediterranean woodland habitats.

ACKNOWLEDGMENTS

I thank Carol LeBoy for the typing of the manuscript and Noel L. Diaz for the graphic arts work.

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FIRE FREQUENCY AND SITE DEGRADATION [1]

Richard J. Vogl [2]

Abstract: Fire frequency is inversely proportional to fire intensity. The natural fire frequencies must be determined to relate changing frequencies to site degradations. Site degradation can be caused by increased and decreased fire frequencies. Altered fire frequencies do not necessarily lead to site degradations. Deviations from normal fire frequencies are usually associated with grazing, cutting, clearing, and man-made droughts. Natural vegetational shifts take place in some ecotonal types and are not degradations. Natural degradation takes place in semi-arid canyons, but is a necessary part of nutrient cycles that allow the canyons to recover and flourish.

Key words: Fire frequency, site degradation, natural fire frequencies, natural degradation.

INTRODUCTION

Mediterranean-climate ecosystems tend to support similar vegetation types regardless of location and the species present. These systems are generally adjacent to, and form transitions (ecotones) with deserts, grasslands, savannas, and woodlands or forests of semi-arid woody trees. Fires of natural origins appear to be an important component of these systems.

Site degradation in these systems must be defined in order to evaluate the relationships between fire frequency and site degradation. Site deterioration takes place whenever the vegetation type best suited or adjusted to a given location is displaced. This best-suited vegetation is sometimes called "on-site" vegetation, implying that it is the evolutionary winner of a juggle for dominance of a given locale, and has occupied that place historically. Site deterioration also occurs when the physical environment is altered so that the original vegetation type cannot immediately reinvade, or cannot regain its previous status. Soils, topography, and hydrology are often adversely affected.

Many definitions of site degradation have embodied within them a degree of anthropomorphism, that is, of assigning human values and price tags to the physical and biological components of the systems under evaluation. Economic values are assigned to such things as livestock forage production, water yields, wildlife productivity, erosion control, recreation use, wood production, and other resources and uses. In some cases, the sites have not deteriorated physically or biologically, but are, nonetheless, considered to be degraded because a particular resource important to man has temporarily declined or changed.

Sometimes the fiscal considerations are even conflicting. While one group is pleased with preventing fires in chaparral, for example, boasting of reduced run-off, stabilized slopes, and erosion control, wildlife managers lament that the big-game habitat has deteriorated, for old-growth chaparral means drastic reductions in big-game as well as general wildlife production.

Changes in fire frequency that produce vegetational changes and possible environmental alterations usually relate to fire intensity as well, since fire frequency is almost always inversely proportional to fire intensity.

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[1] Presented at the Symposium on Environmental Consequences of Fire and Fuel Management in Mediterranean Ecosystems, Palo Alto, Calif. Aug. 1-5, 1977.

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DETERMINATION OF NATURAL FIRE FREQUENCIES

> An ecologist must look at each landscape with a time and process perspective.
>
> Paul Sears 1977

The natural fire frequencies must be known to determine if site degradation has been brought about by a change in fire frequencies. One of the most important tasks that ecologists must undertake is the determination of the natural fire frequencies for each vegetation type, if fire management is going to progress (Kilgore 1976). This can only be accomplished by studying the original (pre-white settlement) vegetation or the vegetational records, and by understanding the vegetational histories of the various habitat types.

Vegetation development/succession is a continuous dynamic process that must be considered in long-range terms or in a historical context. In order to understand the role of fire, one must understand the original vegetation under natural conditions.

Contemporary trends in ecology have been stressing experimentation and modeling while neglecting vegetational histories as valuable scientific endeavors. Vegetational histories are currently in such disregard that few are attempted or published (Whitford 1977). Apparently, trained ecologists have forgotten, and novices haven't learned, that ecologists, like archaeologists and paleontologists who study the past, and geologists and other field scientists, must rely more on logic and observation/interpretation, particularly when dealing with historical events, than strictly experimental/laboratory scientists. Such descriptive or qualitative information is just as valid and important, particularly as it accumulates through time, as are the conclusions drawn from experimentation. We should be learning from the past and building upon the accumulating knowledge obtained by whatever methods, rather than repeating ourselves by having to rediscover again and again what was already known but discarded because it was not done "scientifically".

> The ecologist's task is not only to see what is there, but to see what is going on.
>
> Paul Sears 1977

SOUTHERN CALIFORNIA CHAPARRAL FIRE FREQUENCIES

Reconstruction of past fire frequencies is complicated by a paucity of records and the presence of man-caused fires. In addition, records and data can be misleading and misinterpreted. State and federal fire records, for example, generally indicate that man-caused fires are most common at the lowest elevations, and that lightning-caused fires are most frequent and important at the highest elevations (J. E. Keeley, personal communication). An obvious assumption based on these data is that upper-elevational chaparral and forests should have had the higher natural fire frequencies. But the picture changes when it is realized that a critical portion of the records are missing, that is, the number of lightning-caused fires that have occurred in the valleys. Most state and federal forest lands only enclose the major mountains and do not include the foothills, upper alluvial fans, and the valleys, or their fire records.

The natural vegetation of southern California was formerly more contiguous and continuous, so that a little lightning could go a long way since fires could travel long distances before reaching physical obstructions. The valleys usually supported oak savannas or woodlands. Common oaks included the valley (*Quercus lobata*), coast live (*Q. agrifolia*), interior live (*Q. wislizenii*), blue (*Q. Douglasii*), and Engelmann oaks (*Q. Engelmannii*) which were subject to heart rot after injury. Sycamore (*Platanus* racemosa) and California walnut (*Juglans californica*) were locally important.

When lightning is the ignition source, the number of fires that persist and spread is more important than the number of strikes. Contrary to popular belief that seems to die hard, southern California lightning is not restricted to the high mountains, but also commonly strikes in the valleys and lowlands. Lightning does not exclusively strike the tallest object in a region such as the tallest tree on the highest mountain, but rather tends to strike the tallest object in the immediate vicinity of where a random lightning discharge occurs. The tallest objects in the early California valleys were the large, open-grown oaks and other trees that stood the brunt of previous lightning strikes and innumerable surface fires. As a result of these agents, along with wind, insects, and fungi, the older trees eventually became scared with basal fire wounds, extensive heart rot, punky wood, and broken limbs; perfect specimens to sustain lightning ignition during heavy rains. The oaks have now been largely replaced by power

poles, transformers, substations, buildings, and exotic trees that are still struck but seldom lead to vegetation fires.

Lightning occurs less commonly in the valleys than in the mountains and is usually accompanied by heavy rains (Weide 1968), but nevertheless, occurs almost every year in most lowland areas, and over a 20-year period will have occurred in almost every month of the year. Detailed investigations of regions in which lightning has been considered to be negligible or unknown usually show these former appraisals to be underestimates, and California's lowlands are no exceptions.

The oaks invariably were surrounded by mid-sized, perennial bunch grasses, graminoid monocots, and forbs with tops dying back to ground level for more than half of each year because of the Mediteranean-type climate. These grasslands covered the plains, valleys, and foothills and could carry a fire within hours or the day following a drenching thunderstorm leaving behind unscathed grass root systems and stimulated meristems (Vogl 1974). The grasslands are now all but gone, the native species have become very uncommon; replaced by cities, farms, and annual-grassland pastures that are interrupted by a myriad of roads, freeways, aqueducts, and other obstructions.

These fires probably burned the grasslands on a yearly basis, with fires reaching the chaparral-covered foothill and mountain slopes nearly every year. Most of the valleys and plains of southern California are extensive, and it would only take that one "exceptional" persistent, lightning strike to spread and burn an entire valley grassland. Harper (1913) pointed out the widespread influence that even rare lightning ignitions could have on longleaf pine country.

> Of course this would not happen (lightning-started fires) very often on any one square mile, perhaps not more than one in one hundred years, --- when there were no roads or fields to stop it, a fire started by either cause might spread over 100 square miles, and if that were the case the average frequency of fire on any one square mile would be about once a year.

It doesn't take much imagination to realize that even uncommon lightning ignitions in the southern California lowlands could also have had profound effects on the vegetation.

Before white settlement and unintentional or intentional intervention, chaparral fires originated from ignition sources in the valleys below and the higher elevations above. Lower-elevational or "warm" chaparral probably had fire applied to it almost annually as fires reached it from burning valley grasslands/savannas (Vogl 1976). But because of a number of factors such as the season of the year, moisture conditions, fuels, stage of vegetational development, time since the last fire, climatic conditions, and other known and unknown reasons, "warm" chaparral only burned on the average of about once every 20 years. Ignition was probably reliant on many factors being just right or conducive to the spread of fire at the time of its contact, with the number of critical factors decreasing with time after the chaparral reached maturity.

Upper-elevational or "cold" chaparral was usually reached by surface fires that periodically swept the understories of the high-elevation coniferous forests. Although lightning strikes are more frequent along the higher peaks and ridges, the conifer trees are less effective in sustaining lightning ignitions during rains. There are, however, a greater number of lightning strikes that are not accompanied or followed by rain there, than in the valleys. The lower fire frequencies of about once every 10 years, as compared to the annual fires of the valleys, was brought about by the more discontinuous nature of the vegetation and the fuels (primarily surface litter accumulations) which prevented the extensive spread of these fires. Within the California conifer belt, the natural fire frequency was probably lower, and the average size of fire smaller, in the southern ranges and Sierra outliers, as well as at the higher elevations.

Again, a number of factors and conditions acting in concert were undoubtedly necessary for the more frequent fires of the conifer zone to spread into the "cold" chaparral once a century or so. Another possibility is that particularly hot fires spread into the "cold" chaparral when extreme fire conditions coincided with overmaturity of the upper-elevational chaparral. Under natural conditions, the less xeric climatic conditions and the longer time it took "cold" chaparral to reach community maturity and decadence were a deterent to fire.

It should be remembered that the average range of wildfires of today cannot be compared with those of yesterday, because the mild and

low-intensity fires which were probably very common in the past are excluded today. Most present-day wildfires are not nature's way, but are nature's alternatives to man's interventions.

INCREASED FIRE FREQUENCIES

Increased fire frequencies are usually man-caused and must often be encouraged because of the fuel-free, and therefore, fire-free periods that characterize most post-burn brushland sites. Increased fire frequencies are often possible because of vegetation changes or the presence of exotic species that thrive with repeated disturbances. The changes that most often permit increased fires are conversions to the adjacent or ecotonal vegetation types which are adjusted to higher fire frequencies.

In aberrant or degraded forms of the original vegetation type, one wildfire often leads to another, in that a given fire "sets up" the area for another fire. This is particularly true when shrub stands burn while they are young and productive. Then the shrubs are so green that a fire, if it can be started, usually results in killing, but not consuming, the foliage, branches, and trunks. The dead stems and branches usually remain standing, eventually dropping their leaves, twigs, and bark thereby creating ideal fuel conditions for a following fire. This post-burn preponderance of dead fuels can lead to another premature fire. In some sites and under certain conditions, then, one premature fire can lead to changes that will promote another premature fire and so on, which in turn, can alter and eventually degrade the site. It should be noted that in some brushland types, a certain percentage of the larger fuels are normally left standing until the next fire under natural fire frequencies. Perhaps these standing stem stubs not only facilitate the spread of the following fire by providing dead and dry fuels, but also serve as a nutrient reserve.

A number of changes are brought about with increased fire frequencies. Recognizing that there are exceptions, the following generalizations can be made:

Increased fire frequencies:

a.) Favor resprouting perennials over non-sprouting species. If species that rely solely on seed germination for recovery are burned before they produce seeds, they may be eliminated.
b.) Promote herbaceous over woody plants.
c.) Promote grasses and forbs.
d.) Often favor aggressive alien over native species.
e.) First increase species diversity--but if carried to extremes can create pure stands.
f.) Lead to decreased fire intensities -- lighter fires occurring more often.
g.) Increased water yields; but if carried to extremes can lead to erratic water flow.
h.) Shortened recovery times to the new type that invades or takes over.
i.) Increase animal productivity; both wild and domestic -- provided that fires are not too frequent.

It should be made clear that increased fire frequencies do not automatically lead to site degradation. Under natural conditions, increased fire frequencies were probably more common than decreased frequencies. When increased fire frequencies lead to natural type conversions that are adjusted and maintained by the more frequent fires, the new regimes do not necessarily affect the sites adversely. Brush to grassland conversions, for example, may actually lead to site improvements, in spite of the increased fire frequencies. But if excessive burning is continued on brushlands that are not converted to grasslands or are not invaded by alien plants, it can lead to drastic reductions in plant cover, deterioration of the organic soil layer, erosion, and eventual site degradation or degraded shrublands.

DECREASED FIRE FREQUENCIES

Fire frequencies are often postponed in American chaparral because of concerted fire protection efforts. The most common changes produced by reducing fire frequencies include:

a.) Increased fire intensities that are directly proportional to the time beyond the normal occurrences.
b.) Increased fuel accumulations -- abnormal buildups of dead and dying plant material.
c.) Widespread plant decadence, species senility, and community stagnation.
d.) Declines in species diversity, particularly in short-lived shrubs, grasses, and herbaceous plants.
e.) Declines in plant productivity and plant vigor -- decreased herbivore/wildlife production.

f.) Decreased water yields -- water flow becomes low but steady.
g.) Excessive loads of gravitational materials that have been temporarily detained by plant growth on steep slopes (above the angle of repose).
h.) Slow recovery after burning -- poor resiliency.
i.) Due to fuel accumulations and plant decadence, fires produce numerous hot spots and "sterilized" places where heat damage to soils has taken place... excessive non-wettability of soils -- severe erosion and soil movements on steep sites following fire.

One of the reasons that Mediteranean-climate fires are considered to produce adverse effects and are viewed as generally destructive may be that most of the observed fires occurred some time beyond their normal sequence, and therefore, were abnormally severe.

FIRE FREQUENCIES AND OTHER FACTORS

Wide deviations from normal fire frequencies do not occur in isolation, but are usually intricately related to other man-caused alterations. These changes occur as man makes use of the brushland resources, or attempts to convert them to what he deems to be more useful.

Shrub-dominated vegetation is commonly used as marginal grazing/browsing areas for livestock of all sorts. Shrub stands are often opened and degraded by livestock. These activities can lead to unintentional reductions in fire frequencies by reducing fuels, breaking up or interrupting otherwise solid stands of shrubs, and by removing the more palatable and flammable while promoting the non-palatable plants which may also be less flammable. The vegetation can recover and even be stimulated by fire, but when combined with heavy, continuous overgrazing can often lead to site degradation. In many parts of Mediteranean-climate ecosystems, frequent fires and grazing are inseparable.

The coastal scrub or sage scrub of California (excluding the coastal succulent scrub of Baja California) is an example of changing fire frequencies as a result of livestock activities. This vegetation type presently occupies scattered coastal plateaus, lower elevational sites, and isolated stands in California's coastal mountains. It is characterized by soft-leaved sub-shrubs, semi-woody shrubs, and herbaceous plants of a highly aromatic nature due to the presence of volatile monoterpenes (Mooney 1977).

When this vegetation type is examined in a historical context, and areas of different grazing intensities are compared, it is apparent that coastal scrub has been largely created by heavy livestock grazing and overgrazing. These sites were usually near natural or man-made water sources. The areas are generally accessible to livestock from the valleys, canyons, or plains on gentle to moderate slopes. Most coastal sage scrub areas were created at the expense of native, perennial bunch grasses (Heady et al. 1977) which were eliminated by overgrazing. As the more palatable grasses and forbs were reduced and eliminated, the pungent, non-palatable sage species expanded. Most of the isolated mid and intermountain scrub stands relate to former grassland, potrero, or ranch sites which focused former livestock utilization in the otherwise undesirable chaparral lands. The concentrated components of the present-day coastal scrub were formerly scattered isolates in the chaparral and grasslands.

In addition to the selective pressures exerted on the vegetation, most of these sites were degraded by trailing, trampling, and compaction which resulted in increased run-off and erosion. This led to the eventual destruction of the grassland soils, created areas of exposed substrate, and made the sites more xeric. This was complicated by the eventual invasion of alien grasses with characteristic bare zones.

All of these changes affected fire frequencies and intensities. Surely the original perennial grasslands burned frequently, with repeated fires helping to maintain the grasslands and to check invading shrubs (Vogl 1974). But with conversion to sage scrub and deterioration of the sites, fire frequencies must have been reduced because of the lowered biomass, reduced fuels on the ground, and discontinuous nature of the vegetation.

In this instance, site degradation was caused by livestock grazing which resulted in changes in fire frequencies, and it is apparent that changes in the fire frequency did not directly produce site degradation. An increase in fire frequencies in coastal scrub, if coupled with the removal of livestock, might actually help to restore sites to grassland. Apparently some land managers have decided to recognize coastal scrub as a natural habitat type, and might, therefore, consider its reconversion to grassland as a site degradation.

Another activity that is often related to site degradation is the cutting of brushlands. Cutting for firewood, fencing materials, and other uses has had important impact in various parts of Mediteranean-climate systems, particularly near population centers in underdeveloped countries and in densely inhabited rural areas. Cutting is often coupled with burning and intensive grazing/browsing which usually causes vegetation degradation through a selective loss of species. Often cutting exceeds regeneration or substantially weakens certain plant species until they die. Woodland tree species have been eliminated from areas adjacent to settlements. Many shrubland areas have been, and still are, being converted to degenerate brushlands. Again, altered fire frequencies are just one facet of the degradation process. In many countries, prime agricultural areas are inadequate and the more marginal brushlands are being pressed into various uses.

Brushland clearing takes place for various reasons and in varied amounts. In developed countries, this clearing is often done on a large scale using herbicides, bulldozers, chains, mechanical crushers, and windrow or brush-pile burning. It should be noted that fire is only one of the many tools used in the clearing, and usually involves the combustion of abnormal fuel loads (piles of brush, stumps, and root systems). If the purpose of the brush clearing is a type conversion or the construction of fuel-breaks for fire protection, the sites are further altered by the planting of different species and follow-up herbicide treatments. Sometimes these cleared sites are subject to intensive erosion before they are recaptured by the planted or invading vegetation. In many cases, brush clearings and type conversions end up as projects of working against nature, because the planted vegetation is quickly reinvaded by the brush, or is only maintained with great effort and expense.

DROUGHTS: MAN-MADE AND NATURAL

Normally, Mediterranean-climate ecosystems are visited by frequent droughts, and the vegetation is able to adjust to these stress periods. The question as to whether natural fires typically occurred during droughts is unresolved. It is obvious that man-caused fires commonly occur during the hottest and driest times today, while severe drought periods in the past may have remained largely fire-free because of the absence of thunderstorms with lightning ignition. When droughts were interrupted by natural ignition, they were probably most often also terminated by rains which greatly enhanced post-burn recovery.

A nearly universal problem today is the intensification of natural dry periods by the lowering of water tables, increasing run-off, and the reduction of stream flow. These factors place additional stresses on the vegetation that may affect its resiliency. Man-made fires during natural droughts, or when man has intensified water problems, may adversely affect the post-burn vegetation, in that the recovery of certain species may be impaired. This in turn, could lead to site degradation, but would relate more to the conditions under which the fire occurred, and not any particular changes in fire frequency. Fire frequency, then, is not only related to fire intensity but also to the time of occurrence of the fire.

NATURAL DEGRADATION

Some sites undergo natural degradation with fires of natural frequencies. In these locations, fires retrogressively set back plant succession/development, in addition to providing temporary conditions conducive to massive physical changes.

Natural degradation, for example, occurs in most canyons supporting perennial streams in southwestern North America. The canyons are usually steep-walled dissections of semi-arid plateaus or rugged mountains. Most of these canyons support dense growths of dry-mesic to mesic species, including thickets of phreatophytic shrubs, trees, and aquatic plants under prolonged to year-round growing seasons. Many of the canyon inhabitants are more characteristic of less arid to mesic climates elsewhere in North America.

The long-growing seasons and ever-present waters promote prolific growth which eventually becomes so abundant that it physically impairs and stiffles additional growth. There is no way for these species to continue to grow and prosper in their own wastes, and these mesic species are unable to invade and survive in the arid environments outside of these canyons.

Eventually, the plant growth becomes decadent, and new growth becomes almost nonexistent. The deciduous trees that are usually present are particularly important sources of fuel. Their fallen-leaf accumulations often create continuous trains of fuels that allow higher-elevational fires to penetrate the canyons. Jungles and tangles of dead and dying vegetation, debris pile-ups, opening canopies, and insufficient water lead to summer water stresses and inevitable fires that convert most of the above-ground

accumulations into ash and charcoal.

Since many of these species do not have the resiliency of fire vegetation types, and the surrounding upland vegetational recovery is often delayed because of arid conditions, the canyons are subject to intensive run-off which results in flash floods, even with average rainstorms. The heavy fuel loads in the canyon bottoms often generate such intense fires that even widely-scattered plants growing on the canyon walls or slopes are consumed. The floods that commonly follow Southwestern canyon fires tend to be severe, causing extensive movement of substrates, even rocks, so that the canyon bottoms are scoured, excavated, recut, and redeposited. The finer materials such as the ash, charcoal, organic matter, and unburned plant parts are generally removed from the canyons and deposited in the lower-elevational floodplains, valleys, and sinks. Even root systems of the trees, shrubs, and herbaceous plants are often excavated and redistributed.

Immediate post-fire and flood assessments usually reveal multiple damages and negative impacts; seemingly clear cases of site degradation. If the fire-flood episodes are considered from a long-term viewpoint, however, they can be seen as part of a cycle that has been repeated innumerable times. How else could such steep-walled canyons have been cut through time? Could these canyon-bottom plants have continued in their own wastes? Or does a fire/flood sequence serve as both an end and a beginning by re-creating hospitable terrestrial and aquatic conditions? The species that are lost in the fire and flood are able to reinvade and again flourish because of the rejuvenating effects of the fires/floods.

But what of the losses of the accumulated products of photosynthesis; the nutrients and minerals in the ash, charcoal, and organic matter that are scoured out of the canyons and deposited in valleys? Surely, this represents a loss of valuable and critical nutrients and is a real degradation of the canyon sites; a logical conclusion when a canyon is viewed in isolation.

But when canyons are considered as parts of larger systems, the organic matter manufactured and accumulated there cannot be readily recycled until it is removed from the canyons. Fires convert these plant materials to easily transported and assimilated forms. Without fires, the floods tend to be less severe since run-off is reduced and impeded, thereby standing little chance of "blowing out" or removing the vegetational accumulations. Loose debris in vegetated canyons quickly piles up during floods, creating debris dams that check the down-rushing waters. Even if floods were successful in excavating plant parts from canyons, the bulk materials delivered to the more arid basins would be of little use for new growth because it would be preserved rather than decomposed. In addition, most of the heavier plant materials would be buried, just as unburned tree and shrub roots are often reburied in floods.

The ravaging floods that usually follow fires in these canyonlands, however, readily carry the bouyant ash and charcoal to the floodplains, lowlands, valleys, and sinks. Flood waters quickly lose their velocities or heads as canyons open to the lowlands, discharging the flood waters into anastomosing channels, dissipating and infiltrating as it reaches level terrain, thereby spreading ash, charcoal, and fine organic-matter flotsam on the surface. This bouyant component is usually transported in an emulsion, detergent-like foam, that prevents burial and guaranties widespread surface placement. The non-wettable nature of these fire products also contributes to their bouyancy.

Once these dust-like materials coat the floodplain and valley sands, silts, and salts, they are vulnerable to wind transport, which could not occur within the protected confines of the deep canyons. Winds commonly rake the lowlands and valleys unimpeded, even generate their own "dust-devil" thermals, reaching maximum velocities during the movement of fronts, and particularly, during thunderstorms. A small fraction of the combusted materials is often also removed from the canyons in the ascending smoke plumes of the fires which sometimes develop directly into cumulus cloud towers.

Once these burned plant materials are carried aloft, they can encircle the globe and be moved back up into mountain watersheds, coming to earth by gravity or as the nuclei of moisture and rain drops. Upon reaching the earth they can be immediately incorporated into the system, eventually working their way through the canyons again, thereby completing the cycle. During active thunderstorm periods, which would normally also produce lightning ignition, most particulate matter would not travel far before it would be captured in a thunderstorm cell and be brought to earth again.

Although man with his typical short-sightedness, educational and cultural prejudices, and pragmatic monetary orientation may consider such fire/flood sequences as

environmental degradations, and attempts to prevent them, the result will be that all of those phenomena, processes, and organisms that are a part of this cycle will be adversely affected. And if prevention is successful, man will have to adjust to nature's alternatives which may be more difficult than working with nature from the beginning.

Although the examples presented occur in southwestern North America, canyons in other arid and semi-arid parts of the world probably function in similar ways.

NATURAL VEGETATIONAL SHIFTS

Some "edges" or transitional regions are apparently more or less stable, consisting of interdigitating species from the two contrasting vegetation types or a juxtaposition of the various vegetational elements with each species seeking out its specific microenvironment.

But other transitional areas are unstable, dynamically fluctuating from one vegetation type to another, depending upon the presence or absence of environmental conditions and the exertion or relaxation of certain factors, including fire. These vegetation types are like battle fronts, with species retreating and advancing with mortality and recruitment, varying from one vegetation type to the other naturally. When fire and other factors lead to such site conversions they cannot be labeled as site degradations.

SUMMARY

> Many people seem unwilling to discard the paradoxical philosophy that while natural landscapes are beautiful, some of the forces that shaped them - such as fire - are undesirable.
>
> B. Riley McClelland. 1975
>
> Western Wildlands

By way of the previous examples, it is apparent that almost all cases of variations in fire frequency cannot be related to site degradation without considering other factors and conditions. One of the things that has confused and delayed the solution of fire problems in the past has been attempts to oversimplify situations, or to blame one particular activity or factor. Often, individuals and agencies have been so certain that fires of any kind are the sources of all problems, that further investigations and considerations are not made.

Cultural values often appear to enter into the evaluation of sites and fires. We are taught that certain things and conditions are acceptable or unacceptable, whether they are practical or aesthetic, and we make judgements accordingly. Intolerance of burned landscapes is brought about by social-cultural conditioning. When most people discard their learned values, for example, they begin to admit that the sights, smells, and sounds of fire and smoke, as well as charred wood or burnt grasses are not only acceptable, but are actually pleasant and even enjoyable. The basic instincts that tell us to accept fires and burned landscapes as a normal part of our surroundings, instincts and feelings that go all the way back to our roots, have been over-ridden by social conditioning and education to reject burning and blackened landscapes, to abhor them, and to be intolerant of them. As a result, the role of fire in site degradation is often exagerated and approached negatively, if not in a biased manner. Fire unfortunately is more often viewed as a destructive menace than as a natural process or phenomenon (Vogl 1977). Fire damage, for example, is still commonly appraised without consideration of the beneficial aspects, which should be subtracted from the damage to yield the net damages or net benefits.

In order to evaluate the effects of fire, including the role fire frequency plays in site deterioration, the obvious and the obscure, and the long-range as well as the immediate effects must be considered. In Mediterranean-climate ecosystems which have evolved with fire and are inseparably related to it, the key to understanding the beneficial and detrimental activities of man as they relate to fire, is to understand the role that fires have played under natural conditions.

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INSTITUTIONAL CHANGE AND FIRE MANAGEMENT[1/, 2/]

Robert G. Lee[3/]

Abstract: This paper examines how social organization facilitates control over wildfire. A theory of institutional change is used to interpret the history of social organizational efforts to regulate fire in California's wildlands. Three types of institutions are described: (1) local volunteers that provided the primary means for fuel and fire management in the first eighty years of the State, (2) fire control bureaucracies that have provided fire protection for the last fifty years, and (3) possible new organizational means for integrating fire and fuel management with other land management activities. It is concluded that, in addition to more scientific and technical knowledge, institutional changes will require new commitments by individuals and the realignment of organizations with new interests.

Key words: fire and fuel management, wildfire, sociological, institutional change, social organization.

INTRODUCTION

This symposium is not simply a transitory meeting of scientists concerned with the role of fire in Mediterranean ecosystems. From an historical perspective it represents something far more significant. Scientists and managers concerned with wildland fire and fuel management have been meeting with increasing frequency and have been asking fundamental questions about existing and potential wildland fire policies. The seriousness with which these questions are being asked signifies that society is enmeshed in a transition from a period in which it has attempted to gain absolute control over fire -- epitomized by the pursuit of fire exclusion policies -- to a period in which it will attempt to regulate fire and human relationships to it through a complex combination of strategies. The term integrated fire management has been used to describe a new approach in which the goal is not simply to limit the number and size of fires, but is instead to minimize social losses and maximize gains by employing various combinations of fire suppression, fire prevention, fuel management, controlled burning, and land use planning.

Scientific and technical information will be needed to develop an integrated approach to fuel and fire management. Basic knowledge of fire and its influence on the biological and physical processes of wildland

1/ Presented at the Symposium on Environmental Consequences of Fire and Fuel Management in Mediterranean Ecosystems, Palo Alto, California, August 1-5, 1977.

2/ Research leading to this report was supported by the OFFICE OF WATER RESEARCH AND TECHNOLOGY, USDI, under the Allotment program of Public Law 88-379, as amended, and by the University of California, Water Resources Center, as a part of Office of Water Research and Technology Project No. A-058-CAL and Water Resources Center Project UCAL-WRC-499. Support was also provided by the California Agricultural Experiment Station, Berkeley, California.

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ecosystems is absolutely essential. Technical knowledge is equally important. Yet, despite its importance, all this information is by itself insufficient for the rational development of any new approach to fuel and fire management. To be successful an integrated approach must also take into account the institutional framework within which such scientific and technical information will become relevant to decision makers.

This paper will begin with a definition of the term institution and an interpretation of institutional change. A discussion of the evolution of institutions responsible for wildfire in California will follow. Emphasis will be placed on the ways social organizations respond to changes in their social and biophysical environments. The discussion will conclude with a few recommendations for changes in administrative organizations that are likely to facilitate the development of an integrated approach to fuel and fire management.

THE NATURE OF INSTITUTIONAL CHANGE

Rose (1965) defined an institution as

> an organized group of persons having different but coordinated functions with respect to each other and the material things necessary for the cooperation of the group, in which the organization and the material things outlast the individual members and new members can take their places (p. 727).

An institution is not necessarily a formal organization such as the U.S. Forest Service. It can also be as informal and uncodified as a family tradition or a national ritual for celebrating the Fourth of July.

Institutions emerge as corporate entities when there is the development of (1) a legitimated procedure through which members can pursue the goals of the institution, and (2) a legitimated sphere of jurisdiction which defines the problems to which these procedures may be applied (Swanson 1971). Members of institutions have a dual status.

They use their relationships to the whole for the fulfillment of their individual needs -- their special interests. But they also maintain the institution by acting as its agents. The existence of an institution as a corporate entity depends upon its members acting on behalf of it when dealing with other people or the natural environment.

The process by which a group of people with common concerns develops into an institution that can authorize people to act as its agents is known as institution building. In order to analyze how an integrated approach to fire an fuel management is possible at the institutional level, we must first understand how institutions are built to solve perceived environmental problems and how they change in response to changes in the perception of the environmental conditions for which they were built. The distinction between institution building and institutional change is a matter of perspective. Institution building views the development of an institution from the point of its inception, while institutional change views the transformation of an institution from the point of its preexisting structure. A theoretical formulation of institutional dynamics was developed by drawing from the work of several sociologists, most notably Swanson (1970, 1971), Eisenstadt (1968, 1969), Shils (1965, 1968), and Parsons (1960).

Institution Building

The process of institution building may be summarized in six steps. It begins when people discover they share a common problem or threat but lack the organizational means for doing anything about it. People communicate their sense of uncertainty to one another, a process through which they come to feel interdependent and alike. A common appraisal of the situation emerges from this communication, but people do not yet know how to confront the problem. Alternative proposals or plans for action are offered, and the advantages and disadvantages of the various proposals are considered.

The second step begins when an individual or group emerges with a plan to transform the problematic conditions. Power is then vested in the person or persons who are perceived to possess special abilities to bring order to chaotic conditions. Sociologists use the term "charisma" to describe individuals or groups that demonstrate the ability to elicit respect, awe, and even reverence by forcefully transforming reality (Shils 1965). But the leader must also act as a critic of any old organizations in order to establish the independence necessary for creating new forms. At this time the leader also begins to identify external sources of support for the program he envisions.

The third step begins when people recognize that their separate acts serve collective purposes. A sense of the new order is associated with the emerging organization.

Many people become excited by the possibilities for success and commit themselves to particular tasks. Yet not all people who are aware of the emerging order become involved, and many people may resist the new order and criticize the leader's plan and methods for implementation. Resisters may adhere to old patterns or attempt to influence the leader's plan by inserting their own proposals. At this point the leader must actively develop external sources of support for his efforts by demonstrating his charismatic abilities to outsiders. Resisters are brought into the group when elements of their counter-proposals are accepted. As collective purposes solidify, outsiders begin to respect the unusual abilities of the leader and his followers to bring order to chaotic conditions. This provides the leader with additional sources of support that help authorize the implementation of his plan. Once sources of power are secure, there is a separation of the plan from its implementation, bringing about a differentiation in roles between those who formulate organizational policy and those who implement it. The organization is now prepared to assume a life of its own.

The fourth step marks the point where the power lodged with the leader is transferred to the group, and members commit themselves to the common goals by sharing the sense of power to transform environmental conditions. The leader often initiates this process by withdrawing from his central position and accepting the dispersion of his power to members who play particular roles. Group goals and the means to reach them thereby come to have an existence independent of the persons who created them. It is at this point that both members and outsiders come to regard the group as a corporate entity with a life and character of its own. Functions previously identified with the leader or individuals are now routinized in the form of particular roles that lend a sense of predictability to the behavior of the group. The group becomes an institution known both internally and externally for its goals, procedures, sphere of jurisdiction, and sources of authority. If this step has been successful, then outside sources of support developed by the leader will persist through formalized relationships. But the institution building process is not complete until members have gone through some additional changes.

The fifth step signifies the solidification of the organization as an entity independent of its members' lives outside the institution. Members begin to relate to one another in ways that reflect their commitment to the collective purposes, with the result that their behavior is not confined to the limited roles they may have played in earlier stages. People soon come to identify with the purposes and activities of the organization as a whole by interacting with one another as members of the group and by coming to see themselves as others, particularly outsiders, see them. Only after their identities are confirmed will members be prepared to flexibly allocate their attention to the requirements of the institution as a corporate entity. Members are now prepared to function as authorized agents of the group, since they can represent its purposes to outsiders in a manner that is consistent both with its internal requirements and with the ways it serves outsiders.

The sixth step indicates that the institution has been built and can be characterized by explicit goals, procedures, agents who occupy a system of offices, and support from other social groups that provide it with the authority it needs to conduct reality ordering activities. The authority acquired by the group now rests with its agents, for it is the agents who carry out the problem solving activities for the group. Offices are coordinated by the emergence of an administrative system that allocates duties, responsibilities, and channels communication. At this point the leader often reemerges in a statesman-like role. His primary functions are to create and fill offices from informal roles and to suggest courses of action for meeting criticism by outsiders or for maintaining and expanding sources of support. Once established, the institution tends to resist change by perfecting the problem-solving activities for which it was built.

Institutional Change

We have seen how institutions are built to serve as organizational solutions to perceived problems or threats from the environment. As such, institutions are suited to the way people define problems in their environment, and are likely to persist with the same problem-solving activities as long as the perceptions of the environment and its problems remain the same. Yet, as members of the modern scientific community, we know that the actual conditions of organizational environments are changing continuously, regardless of how they are perceived by members. An institution is in danger of losing its effectiveness as a social organizational device when the realities of the environment change and member's perceptions remain the same. Since this seems to have

happened more than once to institutions authorized to manage fire, I will examine the relationship between changing environmental conditions and institutional change.

When change in the institutional environment is very slow the organization can often adapt by meeting new problems with incremental changes in old solutions or with new solutions that follow from old assumptions. But when change in the environment is rapid and unpredictable, institutions often lose their effectiveness. This is associated with internal confusion and conflict that is followed by withdrawal of support by outside groups. At this point the institution's survival is threatened, since both its members and outsiders sense it lacks the means for solving new problems or meeting new threats. Very few organizations actually collapse and dissolve under such stress. What usually happens instead is that loss in the sense of organizational integrity stimulates an attempt to reconstitute the institution.

Reconstitution involves reformulation of the purposes, procedures, jurisdiction, and sources of outside support. It usually takes the form of a repetition of the steps through which the original organization was built. But reconstitution differs significantly from the original institution building process. During reconstitution members retain their generalized commitment to the original organization as a corporate entity at the same time that they lose their commitment to specific purposes, procedures and offices, thus permitting them to test new realities without a sense of alienation from others. This retention of corporate citizenship, with its firm sense of responsibility to the general welfare of the original group, clearly distinguishes institutional change from institution building.

This theoretical framework for analyzing institutional dynamics provides us with a window through which to examine how institutions were built to solve perceived wildfire problems, and how these institutions have changed in response to changes in the perceptions of the environments to which they were adapted.

INSTITUTIONAL ADAPTIONS TO ENVIRONMENTAL CHANGE

An historical interpretation of institutional change in relation to fuel and fire management in California's Mediterranean climate ecosystems will be presented. It will outline the characteristics and actions of past, present, and proposed organizations in relation to their social and biophysical environments. Figure 1 summarizes this information in a format that will structure discussion. Historical case material has been limited to California, because comparisons between institutional forms would become too complex if all the social conditions in other countries with Mediterranean climate ecosystems were included. However, care has been taken to make all the conceptual material general enough so that it can be applied to any form of society at any level of development.

The rows of figure 1 have been organized to provide three sorts of information: (1) environmental conditions that underly the perception of problems or threats requiring an organizational solution, (2) institutional adaptations to perceived environmental conditions, described in terms of the characteristics of a completed organization, and (3) organizational solutions, involving actions to solve perceived environmental problems (inputs to wildland systems).

The columns of figure 1 represent three distinct stages in the evolution of institutions responsible for the control of fires and fuel in wildland ecosystems. The first stage describes the environmental conditions, institutional arrangements, and organizational solutions that existed in local areas prior to the emergence of State and Federal fire control organizations. The second stage describes the environmental conditions which stimulated formation of the fire control bureaucracies that have existed for the last thirty or forty years. The third stage describes the present environmental conditions and theorizes about the best form of institutional adaptation and organizational solutions.

Figure 1 lists two biophysical environmental conditions that have changed significantly over the period of study so that their relationship to institutional changes could be displayed: (1) relative quantity of fuels, (2) the relative number of unwanted ignitions. The number of unwanted fires reflects the number of fires started by people as well as the naturally caused.

Four characteristics of the social environment are summarized under environmental conditions: (1) the relative number and value of resources associated with wildlands, (2) the relative losses to resources from wildfire, (3) the relative gains from using fire as a tool to protect or enhance resource values, and (4) the relative amount of scien-

tific and technological information available on fuel and fire management in natural ecosystems. Consideration of resource values reflects several important conditions, including population growth, expansion of populations into wildlands, increases in the number and diversity of interest groups concerned with wildlands, and increased access to wildlands by user publics. All environmental conditions are expressed on a relative basis so as to facilitate comparison of institutional adaptations.

Five attributes are used to summarize the organizations at each stage of institutional evolution: (1) organizational goals, (2) complexity and flexibility of procedures, (3) sorts of agents, (4) source of authority (legitimate social power), and (5) the locus and continuity of authority in the organization. These attributes characterize organizations that have completed the institution building process. Discussion of these characteristics for each institutional stage will involve a sketch of how particular forms of organization arose as adaptations to perception of the environmental conditions.

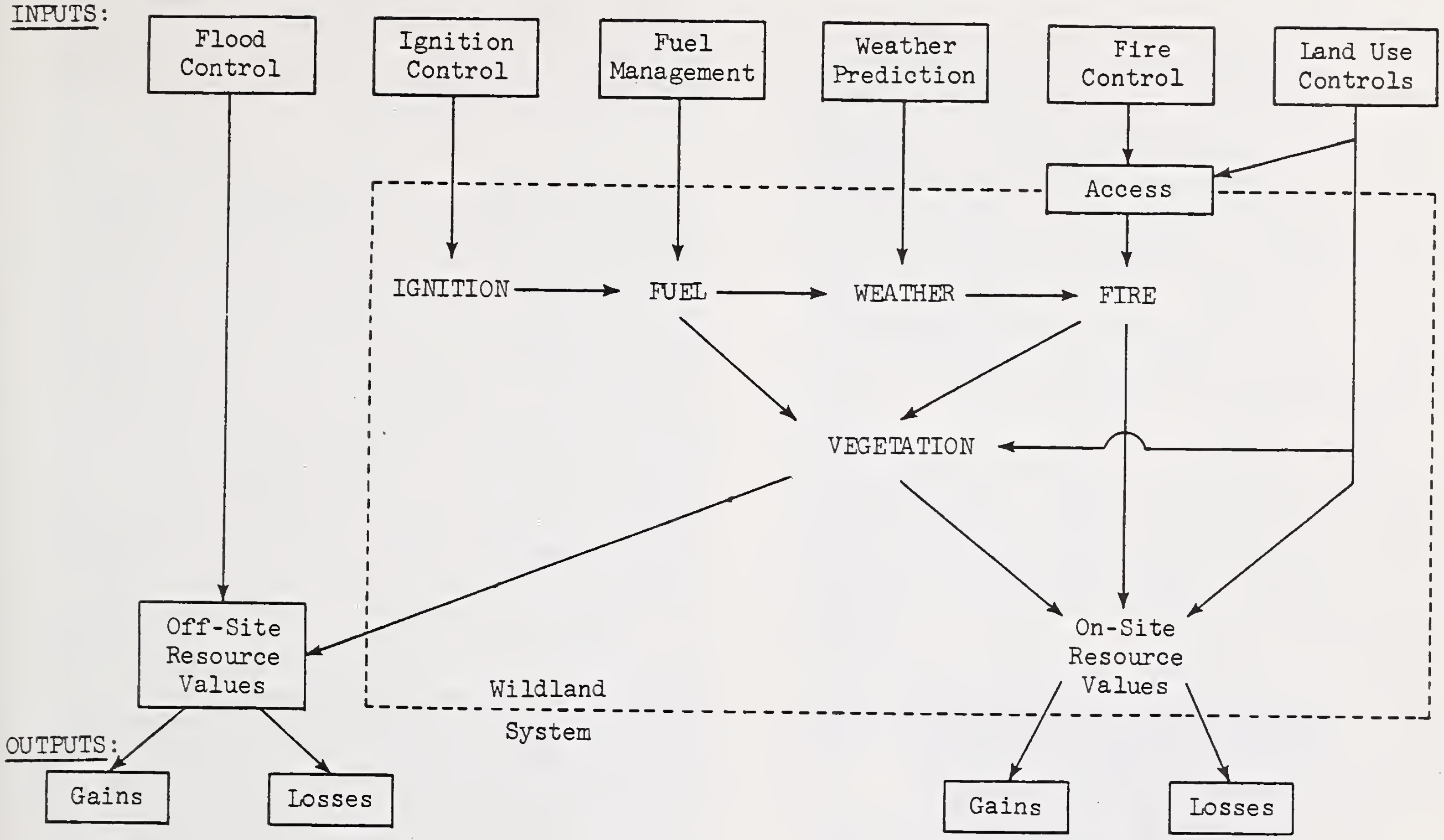
Organizational solutions to fire problems are summarized by six sorts of control over wildland ecosystems and the human activities conducted thereon. These include regulations of (1) unwanted human ignitions, (2) quantity and distribution of fuels, (3) land uses, including both capital developments and natural resource management, (4) flood waters, (5) weather predictions and modification, and (6) wildfire itself. Figure 2 shows these solutions as management inputs to wildland systems. It illustrates the relationships between these inputs and the essential elements of these ecosystems of concern to fire managers. Most of these relationships should be familiar to wildland scientists. However, some of the relationships describing outputs from wildland systems require additional explanation.

On-site resource values that are influenced by fire or its effects can be regulated by land use planning. Such values include land uses such as forest plantations, rangelands, recreational developments, and powerlines. Risks to these values can be reduced through measures such as zoning and the

Figure 1--Institutional stages in the evolution of fire management in California

CHARACTERISTICS OF ENVIRONMENT, INSTITUTION, AND SOLUTIONS	EVOLUTIONARY STAGES		
	STAGE I LOCAL VOLUNTARISM	STAGE II FIRE CONTROL BUREAUCRACIES	STAGE III MULTI-PURPOSE FIRE MANAGEMENT
Environmental Conditions			
Quanitity of Fuel	Low to Moderate	Moderate to High	Very High
Number of Unwanted Ignitions	Moderate	High	Very High
Number/Value of Resources	Few/Low	Few/Moderate	Many/High
Resource Losses From Fire	Variable	Moderate	High
Resource Gains From Fire	Moderate	Low	Very Low
Expertise and Technology	Few	Moderate	High
Institutional Adaptations			
Goals	Resource Protection and Enhancement	Fire Exclusion	Protection and Enhancement of Multiple Resources
Procedures (Complexity/Flexibility)	Simple/Dynamic	Simple/Static	Complex/Dynamic
Agents	Local Volunteers	Single-purpose Task Groups	Multi-agent Management Teams
Sources of Authority	Tradition and Charismatic Persons	Charismatic Actions with Limited Scientific Expertise	Constituency Responsiveness and Scientific Expertise
Locus/Continuity of Authority	Decentralized/Unstable	Centralized/Episodic	Dispersed/Stable
Organizational Solutions			
Ignition Control	Moderate	Moderate	High
Fuel Management	High	Low	High
Land Use Controls	None	Low	High
Fire Control	Moderate	Very High	High
Flood Control	None	Moderate	High
Weather Prediction (and Control)	Low	Low-Moderate	Moderate-High

Figure 2--Regulation of fire in wildland systems



enforcement of regulations that specify practices to reduce the susceptibility of resources to loss by fire. Enhancement of some of the resource values can be achieved through prescribed burning for purposes such as preservation of fire climax species and range or wildlife habitat improvement.

Figure 2 shows a distinction between these on-site resource values and off-site resource values falling outside the wildland system but influenced by the effects of fire on water flow, soil movement, and air quality. The fact that these values are affected by the outcomes from fire rather than by fire itself allows for much greater flexibility in the application of technological solutions. This is illustrated by the success of flood control projects downstream from watersheds that burn periodically.

Gains or losses associated with on-site or off-site resource values are shown in figure 2 as outputs from the wildland system. On-site and off-site resources are combined in figure 1 and shown as part of the organizational environment. This represents these losses or gains to resource values as sources of change for building or reconstituting institutions. Yet losses and gains to resource values can, along with the other environmental conditions, also be viewed historically as possible results from the application of past organizational solutions. Thus, figure 1 shows an increase in resource losses over time associated with increases in the quantity of fuel, number of unwanted human ignitions, and the number and value of resources. It seems possible that losses have increased because past organizational solutions did not gain adequate control over fuel buildups, ignitions, or the values at risk, despite the fact that the scientific knowledge and technology pertaining to fire increased significantly.

I will now use the theory of institution building and institutional change to make an historical interpretation of how past and present institutions generated solutions to fire problems of the wildland systems in California. Note that this is only one among many models for interpreting the evolution of fuel and fire management. The present use of this model is more heuristic than explanatory, since we are still actively involved in research to evaluate it. Yet, regardless of its hypothetical status, it already seems to explain far more about the development of fire institutions than other political and social models available in the literature.

Local Voluntarism

An institutional vacuum existed just over a century ago when immigrants began to settle and use the wildlands of California. It was a frontier era in which the functions of government were restricted to granting land for mining or homesteading, enforcing law, and collecting taxes. The national citizenry had learned to associate freedom in economic pursuits with the process of "opening up the West" (Clar 1969). Mining, lumbering, ranching, and farming soon dominated the use of wildlands throughout the State. With a few exceptions, the value of these resources was relatively low.

Many of these early settlers had in the East acquired traditions for using fire as a tool to clear heavy growth of vegetation from land for purposes of enhancing farming, grazing, or logging. Since their primary motivations were for immediate survival or economic gains, they were little concerned with the long-run consequences for the soil or other resources. When they reached California, these settlers encountered an environment where fires burned frequently and often intensely.

Early losses from wildfire had become such a problem that they received considerable attention at the first session of the California legislature in 1850 (Clar 1959). Action took the form of a regulatory law to protect property from damage by fire set through willfulness and negligence. This law incorporated formal legal practices that had evolved along with the traditional rights and duties associated with the use of fire as a tool in states to the east. By placing emphasis on the responsibility of the individual to regulate fire, it established the basic premise of the legal framework that has, with some modification, continued to govern the management of fire on private lands.

The era proceeding State involvement in fire protection did not long remain an institutional vacuum. By World War I there was at least some form of institutional control over fire on most of the wildlands in the State. In 1892 and 1893 the Federal Government initiated fire exclusion policies in California by establishing almost six million acres of Forest Reserves to protect chaparral covered watersheds in the mountains surrounding the rich agricultural lands of the Los Angeles basin. During the following twenty years much of the mixed conifer forest in the Sierra Nevada and the Coast Range was brought under Federal regulation to protect it from fire and trespass. Fire protection on the remaining forest, agricultural and range lands, along with the extensive North Coast forests, was the responsibility of the private landowner. Local institutions developed as landowners discovered that they shared a common problem.

Institution building was most pronounced among settlers who engaged in farming and ranching. These people shared similar interests and had common experiences with fire in California or in states to the east. They tended to associate uncertainty with accumulation of fuels and indiscriminate burning, and found the use of fire as a tool to be the most effective means for protecting their improvements and enhancing resource values. The controlled use of fire was possible at that time, since periodic fires had kept fuel levels relatively low and there were relatively few competing resource values.

Adjoining landowners soon recognized that there were advantages to mutual aid in fire protection and coordination in the use of fire. Individuals with a knowledge of fire and an ability to control it emerged as charismatic leaders in local communities. These leaders coordinated the actions of local volunteers, and in the process perpetuated and modified traditional procedures for controlling fire. Volunteers learned to bring order to a potentially chaotic environment through acquiring relatively simple methods of using fire for a variety of purposes, including hazard reduction, range improvement, and wildfire control.

These volunteers did not seem to doubt their authority to regulate fire, even though the use of fire represented a tremendous source of social power. It was accepted as the right thing to do under the circumstances simply because it has always been done that way and charismatic leaders in the community had endorsed it. However, the form in which this authority was institutionalized differed from the formal organizations we know today. Since people often lived miles apart, and new people were constantly moving into the communities the authority to regulate fire was decentralized and tended to be unstable. Coordinated actions were not possible until new members had acquired a sense of the local problems, traditions, and solutions, and had come to identify with the local group and its purposes. Hence, only a small proportion of landowners ever acquired the informal status of volunteer agents who could act for the community in the use of fire either on their own land or on their neighbor's land. This instability in authority to regulate fire in

the interests of the community, aggravated by rapid population growth and geographic mobility, continued to be a major source of uncertainty for these communities. State and Federal government involvement in fire protection came about when this instability was combined with increases in resource values, fuel levels, losses from wildfire, and available technology.

However, there were a number of areas in the State where local institution building had been particularly successful. As resource values increased, some of these institutions assumed the formal status of citizen fire protection associations. Although they received no local or State aid from tax sources and lacked a legal foundation, they provided the State Forester with the initial elements for an organized system of rural and wildland fire protection (Clar 1969). The most successful of these associations continue to exist today as county fire protection districts, having received initial authority and aid from the State during the 1920's.

Other successful local institutions became the nuclei for a system of cooperative fire protection that was launched by the State in 1920, in which the State provided rangers to supervise all fire protection work within the county. Until implementation of the Clark-McNary Act of 1924, the State's contribution to county fire protection was restricted to leadership. Thus, during its early years the State's program of rural and wildland fire protection relied on the volunteers that arose through local institution building. Significant manpower for fire control did not come under the regulation of the State until the mid- 1930's, when the Civilian Conservation Corps and the Federal unemployment relief programs provided crews for fighting fire on private lands.

The replacement of local volunteers by State directed fire crews was an institutional change that was resisted by local volunteers, particularly those from remote ranching communities. Control over manpower finally enabled the State to implement a strict policy of fire exclusion which deemphasized the use of fire as a tool. Yet, despite the State's efforts to change these local institutions, some volunteers ignored State regulations and continued to practice traditional methods for managing chaparral and rangelands and for converting forests to grasslands. Residual elements of these institutions have persisted to the present, particularly in several North Coast counties.

Fire Control Bureaucracies

At the same time that local institutions were being built to regulate fire on private land, a national institution dedicated to the management of forest lands for the larger public interest was being built under the charismatic leadership of Gifford Pinchot. The forestry profession, expressed most fully through formation of the U.S. Forest Service, was soon authorizing agents to protect the Nation's forest lands from uncontrolled exploitation and wildfire. A major goal of the forester's moral crusade was to exclude fire with all its destructive power, from America's forests. Fire was defined as an enemy -- a "red demon" -- against which foresters must test their heroic strength. Schiff (1962) has shown how this crusade even permeated the Forest Service's research organization, successfully shaping a half century of research designed only to demonstrate the harmful influences of fire on forests.

Figure 3--Early fire prevention poster featuring the "red demon".

Foresters in both the State and Federal government faced very difficult problems during the 1920's. Fire protection had been successful enough so that the quantity and extensiveness of fuels were increasing. The rapid increase in the State's population, in combination with increasing access to and use of the wildland areas was resulting in a larger number of uncontrolled fires each year. Even though the number of important resources had not changed substantially, the

water, timber, and range resources were progressively becoming more valuable. The interaction between the increases in the quantity of fuel, number of fires, and value of resources had resulted in alarmingly high losses and a deemphasis on the use of fire as a tool. With the increased confidence from research, and new technology in the areas of communications and transportation, many foresters focused their attention on the construction of large-scale fire control organizations. Their battle with the "red demon" had now entered a new phase -- a renewal of a weakening crusade that would be aided by the national traumas of the 1930's and 1940's.

The goals and procedures of the emerging fire control organizations were relatively simple. To exclude wildfire from rural and wild lands it was necessary to build a military-type bureaucracy consisting of full-time crews and to provide the crews with the mobility to strike at fires when they were small. An expanded system of lookouts and telephone communications would provide coordination and shorten the lag-time between the discovery of fire and the deployment of crews. The number of fires caused by the willful or careless behavior of people would be reduced dramatically by law enforcement and a public information campaign. The primary agents were special purpose task groups assigned to fire prevention and fire suppression. As is typical for bureaucracies, these agents were restricted to fixed sets of simple procedures for reducing the <u>number</u> of human-caused ignitions and limiting the <u>size</u> of wildfires.

Funding for an expanded fire control organization was at first difficult to secure, both at State and federal levels of government. Within the State there was intense competition for funds between the remote counties and the populous and politically powerful counties such as Los Angeles. California's new fire suppression organizations was struggling to gain control over wildland protection when the Great Depression struck the Nation. Within two years manpower was abundant, and the new California Division of Forestry had "grown lustily" as a result of "forced feeding" by economic relief programs (Clar 1969a). National Forests also benefited greatly from the depression by using crews to develop better access and systems of communication.

Historical circumstances had placed the leaders of fire exclusion in a fortunate position. Their crusade against fire was also helping to heal the economic wounds of the Nation. Tremendous charisma was soon associated with an organization that could provide people with work by controlling the chaotic power of nature. Today we find it difficult to imagine how important it must have been for people to regain a sense of control over their lives and a sense of confidence in and commitment to a strong group that had the power to bring order to chaos. People developed a sense of control over their common problems through working together to control nature. This massive institution building effort turned the disheartened and socially alienated into agents committed to the collective purposes of organizations, particularly the Civilian Conservation Corps. The authority to pursue fire suppression policies on a massive scale soon rested on a broad base of support from members of the general public who had developed respect for the power of these organizations to bring order to both society and nature.

As the Nation pulled out of the Depression and work again became available in the private sector, the highly centralized fire control bureaucracies sought new funding for full-time personnel to replace people who had been made available through unemployment relief programs. California fire protection officials also sought a more comprehensive fire protection system for timber and watershed lands.

But the temporary instability in support ended with the bombing of Pearl Harbor in 1941. The Nation was united in all-out war, and the Division of Forestry and U.S. Forest Service became centrally involved in civil defense preparations against sabotage and enemy invasions. Fire lookout stations were manned to warn against attack by enemy aircraft and fire trucks were placed on stand-by near potential bomb targets. Once again fire suppression organizations were helping to bring order to society at large by controlling fire. Only this time they occupied an even more powerful position than they had during the Depression -- fire, the enemy of the forest, was now associated with the enemy abroad. The chaos of war was associated with the chaos of wildfire, and fire suppression crews became home-front heroes.

Euphoric over decisive victory in both oceans, the Nation turned back to its domestic problems while maintaining a dominant military position in the world and high level of civil defense preparedness at home. The traumas of economic collapse and war had scarred a generation and helped provide the public support needed for building institutions committed to fire exclusion. Now that the institutions were completed, authority for their maintenance and expansion was to be

maintained by periodic reawakenings of the fearful chaos these institutions had been built to combat.

WARTIME FOREST FIRE PREVENTION CAMPAIGN LAUNCHED

A MAJOR drive to aid the war effort by reducing materially the 90,000 to 170,000 forest fires caused annually by human carelessness was launched from Washington, D. C., on July 24. Known as the Wartime Forest Fire Prevention Campaign, the project was planned by the National Advertising Council as a contribution to the nation's war effort, and is being directed by the United States Forest Service in cooperation with public and private agencies throughout the nation. The opening gun was fired by Secretary of Agriculture Claude R. Wickard who presented to the country over a nationwide radio hookup the campaign's theme, or slogan — CARELESS MATCHES AID THE AXIS—PREVENT FOREST FIRES.

ter, have been prepared: 2,000 000 leaflets showing how to put out a match and cigarette are being distributed, as are 2,000,000 cards on which are printed common-sense rules of forest fire prevention. In addition, 20,000 cards for street cars and busses, along with 15,000 billboard displays, are ready to go into action against fire during the vital days ahead. All of this material is in two colors, and displays the symbol and slogan of the campaign—CARELESS MATCHES AID THE AXIS—PREVENT FOREST FIRES.

Two interesting features of the campaign will be broad publicity given forest fire prevention by Paramount Pictures, Inc., in connection with its forthcoming production. "The Forest Ranger," and a fag-bag campaign to be conducted by the Girl Scouts of

Figure 4--World War II forest fire prevention campaign launched in 1942.

Losses from wildfire continued to increase during the 1950's and 1960's, and were often associated with catastrophic fires. Media coverage dramatized the destructive power of these fires, thereby succeeding in reawakening the fear of destruction and chaos on a grand scale. Following catastrophic fires, both the State and Federal governments were generous with emergency fire fighting funds and were more responsive to requests for increases in regular fire fighting appropriations. State support was always easier to obtain if linked to civil defense programs. By providing the opportunity for heroic actions, periodic disasters empowered the fire control organizations to continue pursuit of fire exclusion policies.

The results from the fire exclusion policy became evident to wildland scientists by the 1960's. Fuels continued to accumulate as extensive blankets of explosive material throughout the State. The number of fires started by people continued to increase, despite the unpresidented success of the Smokey the Bear fire prevention campaign (Hoag Associates 1968). But, more significantly, the number of resources people valued in the State's wildlands increased, and both these new resources and the traditional resources had assumed very high values. Interests in recreation had multiplied and diversified. Strong environmental preservation interests emerged to protect endangered and unique resources. The aesthetic properties of landscapes were defined as visual resources. Second home subdivisions and retirement communities spread through desirable wildland areas, often relying on the California Division of Forestry for fire protection.

Losses, even from small fires, increased alarmingly. Use of fire as a tool for hazard reduction or resource enhancement reached an all-time low, since the losses caused by an escaped fire were often substantial. Fire exclusion converged with the legal framework placing responsibility on the landowner, with the result that both public and private landowners became very cautious with the use of fire for fuel manipulation. The primary means of fuel management was mechanical clearing of extensive fuel-break systems with emergency funds that followed disasterous fires. But, once constructed, few of these fuel break systems could be maintained adequately because of the lack of regular funding. There was little control over the increasing on-site values at risk in wildlands because of the reluctance of Federal, State, and local governments to interfere with private property rights or to exercise strict control over the uses of public lands. However, control over off-site values at risk was achieved in many areas by the flood control projects built by the Corps of Engineers. By 1970 outsiders were beginning to question the success of a fire exclusion policy in combination with a legal framework that protected property rights and placed responsibility for the use of fire on the landowner.

Multi-Purpose Fire Management

A new crusade emerged in California during the 1960's under the charismatic leadership of Professor Harold Biswell. This time the emphasis was on the natural beneficial role of fire in forests. Fire was not thought of as an enemy to be excluded, but as an essential component of forest ecosystems that was just as natural as water, air, and soil. Like other natural processes, it could be used to protect and enhance the multiple values people seek from forests. It was argued that the attempt to exclude fire from forests had produced disasterous consequences by permitting fuels to accumulate to unnaturally high levels. At these levels fire would burn the entire forest canopy or would sweep uninterrupted across miles of mature chaparral until it reached a natural meadow or

man-made boundary.

Biswell had learned about the beneficial aspects of fire early in his career while working in the pine forests of the South, and he did not acquire an association between fire and social chaos from his experiences with the Depression and World War II. When he arrived in California he initiated projects to demonstrate the use of prescribed burning in forest management. These projects had to be conducted on private land, since the State and Federal governments adhered strictly to fire exclusion policies. Institution building techniques would not work because fire exclusion had been successfully institutionalized in the form of fire control bureaucracies.

Just as historical circumstances had been fortuitous for the implementation of fire exclusion, they now became fortuitous for its undoing. The war against fire was a crusade of a passing generation. A new cohort of professionals emerged from the 1960's era of war abroad and social chaos at home with the view that destruction and chaos were often the result from the excesses and abuses of power on the part of large social organizations. This view carried over to fire control bureaucracies. The successes from the past had become the problems for the present. Among an emerging generation of professionals this signaled the end of the crusade for fire exclusion and announced a serious movement toward integrated fire management, involving high levels of control over ignitions, fuels, values at risk, fire, and floods, along with more sophisticated means for predicting and controlling weather. The new generation of professionals soon discovered that their predecessors had not fully exploited scientific expertise as a source of authority for fire management, and began for the first time to test theories and practices developed by Biswell and other leaders of the new crusade. Armed with miles of output from computer simulation models, they began to reveal the unanticipated consequences of fire exclusion and to prescribe treatments for reducing hazards and enhancing resource values. Their credibility was enhanced by commitment to Pinchot's original mission of relying on scientific knowledge for managing forests in the interests of Nation as a whole. A loosening of the commitment to fire exclusion became possible for other professionals when these new agents for the larger public interest demonstrated that their purpose was to reduce losses and maximize gains to resource values. New goals and procedures, supported by scientific expertise as a source of authority, opened the door to change in existing fire control organizations. But missing from this new moral crusade was a corresponding sense of realism regarding the possibilities for institutional change. Knowledge of the role of fire in biophysical systems was an inadequate source of authority for organizations that were built and maintained by institutionalizing support from other groups in society. To be successful, a new approach to fire management had to demonstrate how authority could be secured and maintained through developing new and different sources of support from outside groups.

Fire exclusion institutions had emerged to satisfy interests concerned with the destruction of forests and watersheds. With the exception of some range and wildlife interests, who conceded to a general policy of fire exclusion on the condition they could obtain permits to continue using fire for resource enhancement, the traditional interests had been satisfied with rigid adherence to procedures for limiting the number and size of wildfires. But this situation changed with the emergence of many new interests. The new spectrum of multiple wildland interests was united in their view of fire only by a universal fear of its catastrophic power. They differed in their perceptions of how fire influenced their particular resource values.

Environmental preservation interests had joined the new crusade and advocated the use of fire as a tool to maintain ecosystems in the condition they were found when Europeans first arrived. Sport hunters favored spot burning in chaparral to create a diverse habitat for deer and other game, while another brand of deer hunter, "shooters", preferred extensive burning to open up expanses in which the game may be killed more readily. Bird watchers favored protection for old trees and snags. Water interests originally favored fire exclusion on watersheds above reservoirs. But interestingly, many Southern California water interests relaxed their concern with fire exclusion when water was imported from the Colorado River to Northern California. Gravel interests in Southern California began to favor periodic burning that would sustain the production of debris in major water courses. These varied interests illustrated that the simple solutions of the past were not likely to long satisfy the interests of emerging user groups. Hence, today we find ourselves in a situation where changes in the relationships between existing institutions and their clients is the key to implementation of integrated fuel and fire management. It seems that many individuals are willing to loosen their commitment to fire exclusion so

as to commit themselves to revised goals and procedures. But the institutions in which these individuals are members have developed a life and character of their own that depends on charismatic actions for maintaining political sources of support. Concerned individuals will have to seek out new sources of political support to redirect these institutions toward a more complex and flexible program of fuel and fire management.

A promising means for developing a stable base of support for fuel and fire management involves the integration of control over fire with other land management functions. Fire would be viewed as a natural process that needs to be regulated in order to enhance or protect the multiple resource values associated with wildlands. The prescriptions for managing fuel and fire on a particular area of land would reflect the various concerns regarding the influence of fire on resources located there. This procedure would be relatively simple when a single resource was involved. Timber management planning would incorporate the regulation of fuel and fire for the protection and enhancement of timber crops. But interdisciplinary teams consisting of experts in many different resources or problems would be necessary when there was more than one use for the same land area. Most land management organizations are already familiar with the use of interdisciplinary planning as a tool for ensuring that multiple interests are reflected in land management treatments. Public involvement in decision-making is another procedure organizations use to reflect diverse social values in their activities. Evaluation of environmental impacts is yet another means by which organizations are required to anticipate the consequences of particular land management decisions. The prevalence of these practices indicate that fuel and fire management is likely to gain in authority and acceptance by associating with other agents in interdisciplinary groups.

Authority acquired through maintaining on-going relationships with multiple client groups, both inside and outside the organization would tend to be relatively stable. Power would not ride on the vicissitudes of individual leadership, heroic response to catastrophies, or the momentary concerns of powerful interests. The number and diversity of other social groups making claims to their attention would have the effect of insulating fire management experts from the pressures of short-term crises that would otherwise divert their efforts from long-term management programs. This would provide them with the autonomy and independence necessary both for formulating more complex goals and procedures and for seeking out new sources of political support. In other words, I am suggesting that the integration of control over fire with other wildland functions, together with a responsiveness to groups concerned with particular resource values, will bring about the institutionalization of a profession commited to integrated fuel and fire management. There seems to be no other way to empower people to pursue a more systematic approach to the treatment of fire.

While this integration would bring about the centralization of authority regarding fire in the hands of professionals, these new agents would be dispersed throughout the formal organizations which employed them to operate on decision-making teams. The dispersion of specific authorities through a larger organization is necessary if decisions are to reflect the unique mix of values and knowledge that bear on a particular issue. Fire management professionals could then begin to develop political support for making necessary changes in the legal framework both to control the values at risk to loss by fire and to protect landowners from the risks associated with the deliberate use of fire to protect or enhance resource values. Without legitimate social power, fire management experts are sure to remain ineffective in the application of rational solutions to fire problems.

CONCLUSIONS

A theory of institutional change has been used to interpret how people have organized themselves to deal with wildfire in California. This interpretation has shown that people responded to their <u>perceptions of wildfire as a threat or problem, not to wildfire as an ecological event</u>. Moreover, it seems that these perceptions have been closely associated with a succession of historical social problems -- from gaining control over nature in a frontier setting, through responding to the threat of economic depression and war, to gaining control over large social organizations that threaten individual control over the concerns of daily life. Both the definition of wildfire problems and the solutions offered to these problems have reflected the social climate of the time more than the particular social and ecological conditions on the ground. The larger social context tended to determine whether fire would be seen as a threat, tool, weapon, or natural process.

This interpretation raises a serious question about the future of fire and fuel management in Mediterranean ecosystems: Is it possible to develop viable approaches to managing fire and fuels without taking into account the larger social problems of the society to which fire is a concern? Results from this study indicate that an approach to fire problems based only on biophysical knowledge would be ineffective because it would fail to develop authority needed for implementation. An approach that responds to some of the major concerns of particular societies will have far greater chances of success. At this time in American society, a legitimate source of social power is to be gained by giving client groups a greater sense of control over and trust in the large organizations that regulate fire and fuels in wildland areas. Different approaches to acquiring authority are likely to work in other societies with Mediterranean climate ecosystems, since many of these societies face very different sorts of social problems. But, in all societies, a scientifically rational approach to fire and fuel management will only be possible after professionals have been empowered to act as agents for a society by responding to its concerns.

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TRANSFERRING FIRE-RELATED INFORMATION TO RESOURCE MANAGERS AND THE PUBLIC: FIREBASE[1]

Alan R. Taylor[2]

Abstract: FIREBASE, a computerized bibliographic information file developed by the Forest Service, is described. The file features bibliographic citations and informative digests of published and unpublished documents and nonprint items related to wildland fire. File structure, content, and access procedures for users worldwide are discussed.

Key words: wildland fire, information retrieval, Renewable Resources Technical Information System.

INTRODUCTION

Technical and scientific information can enhance the resource manager's ability to make good decisions for managing the world's renewable resources. Proper use of such information also increases public understanding and acceptance of resource managers' decisions. Unfortunately, most resource managers have inadequate access to technical information (Callaham 1976).

The Forest Service and several cooperators are developing the Renewable Resources Technical Information System (RRTIS) that will provide rapid, efficient access to scientific and technical information. RRTIS is being designed as an integral part of a worldwide forestry information network (Callaham 1976, Taylor 1976).

The subject of this paper is FIREBASE, the fire information module of RRTIS. I will describe this database, tell you what it provides, how you can use it, and how you can contribute to its usefulness in the future.

[1]Presented at the Symposium on Environmental Consequences of Fire and Fuel Management in Mediterranean Ecosystems, Palo Alto, Calif. Aug. 1-5, 1977.

[2]Research Forester, Intermountain Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture, Ogden, Utah 84401. Located at the Intermountain Station's Northern Forest Fire Laboratory, Missoula, Mont. 59806. The author was FIREBASE Manager during its development phase, January 1974-September 1976, and is now consultant to the FIREBASE Program Manager.

WHAT FIREBASE IS

FIREBASE is a computerized bibliographic information file. The computer stores and retrieves bibliographic citations and specially written digests of original information on every aspect of wildland fire.

The types of fire-related items referenced and digested for FIREBASE include:

Monographs	Filmstrips
Standards	Games
Drawings	Kits
Films	Lesson Plans
Maps	Microform
Phonorecords	Models
Serial Articles	Motion Pictures
Patents	Pictures
Reports	Machine Readable Data Files
Computer Media	Realia
Letters	Simulators
Speeches	Slides
News Items	Slide/Tapes
Audiorecords	Transparencies
Charts	Videorecords
Courses	

You can see that the file includes many nonprint types of information. That is why I will be using the term "item" instead of "document" throughout this paper.

The database does not contain tabular data sets or "hard" data, but some of the digests describe the kinds, amounts, and sources of data contained in the original items.

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=== 448  ====
<ID         >FB75-0711     B   KY
<TITLE      >Experimental study on the effects of prescribed burning on a Quercus coccifera
L. garrigue: early results.  In Proceedings Annual Tall Timbers Fire Ecology Conference,
No. 13.  Tall Timbers Fire Ecology Conference, Tallahassee, FL, USA, 22-23 Mar 1973.
<AUTHOR     >
<PER AU     >Trabaud, Louis.
<AFFIL      >Centre d'etudes phytosociologiques et ecologiques, B.P.  1018-Route de mende,
Montpellier, France.
<DATE       >1974
<PUB DESC   >p. 97-129.  24 ref.  16 fig.; 1 tab.
<LANGUAGE   >In En.
<SUBJECT    >
<TOPIC      >Prescribed fires; Fire effects; Experimental fires
<KEYSUG     >prescribed fires; experimental fires; succession; chaparral; field experimental
fires; prescribed fires (planned ignition); fire effects
<TAXON      >Quercus coccifera;Brachypodium ramosum;Dorcynium suffruticosum;Rubia peregrina
<GEO        >Europe, Western Europe, France, Montpellier
<ABSTRACT   >
<P          >Over the centuries natural fires in the French Mediterranean have created a
vegetation type known as garrigue, a formation of low (less than 2 meters), fire-resistant,
small, evergreen trees and shrubs.  The study is set in a large, representative scrub oak
garrigue.  The garrigue is stable, and 2 years after burning, a garrigue tends to return to
its original character.  Five years later, a burned garrigue is almost indistinguishable
from an unburned garrigue.  The usual garrigue species sprout from rhizomes.  Annual species
appear shortly after burning, but they are short-lived.  Fall burns, however, tend to favor
the herbaceous species to the detriment of the woody species; the more frequent the
burnings, the greater is this tendency.
<S          >Test plots were established in the garrigue formations near Montpellier,
France, to study the effects of fire on garrigue.  Permanent vegetation lines were set up on
each 10 by 5 m plot.  The lines ran the length of the plots and observations were made
every 10 centimeters along the line.  The surface soil characteristics, vegetation in each
of five different layers (0-5 cm, 5-25 cm, 25-50 cm, 50-100 cm, more than 100 cm) beneath
the observation point, vegetation on the line between the observation points, vegetation
height, and the tallest species were recorded.  The vegetation in each plot was mapped on a
scale of 1 to 100.  Measurements of biomass on four test plots gave the following results:
cut by machine--26 tons per hectare green weight, 5 tons per hectare dry weight; cut by
hand--33 tons per hectare green weight . . . . . . . . . . . . . . . . . . . . . . . . . .
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Figure 1.--Partial computer record showing a typical FIREBASE bibliographic citation with specially written two-part digest of an original item.

WHAT IT PROVIDES

When you request information, a FIREBASE Access Center will search the file and send you computer printouts containing informative digests and citations of published and unpublished items (fig. 1). Each search is carefully tailored to your request. After receiving the printout you may decide that you need to see a full copy of an item. Many of the original items selected for the file are being microfilmed so that, copyright and other regulations permitting, the Access Center may be able to provide you with a photocopy of the original (Taylor and Eckels 1977). If it is necessary to charge for photocopies, you will be notified of the costs before they are incurred. At present, there is no charge for other services.

HOW IT IS CONSTRUCTED

FIREBASE is unique in several ways. It is the only computerized bibliographic database designed for the wildland fire community. Further, its design reflects the expressed needs of hundreds of land managers, scientists, and other potential users who were asked what features they most wanted in a fire database. One example of this is the two-part digest we usually write (fig. 1); these digests contain a < P > or "Principal Message" section, and an < S > or "Specifics" section. A typical < P > section is a plain language, results-oriented paragraph that states the problem, the research, and the study results. A typical < S > section gives methods, parameters measured, mathematical equations, and other specifics. This two-part design makes it easy to grasp the author's results without stumbling over technical jargon.

About one-third of the citations in the file are not yet accompanied by digests. These are called "citation-only" items. Digests will be added to many of these as time and resources permit.

One unusual feature of this and other RRTIS databases is the inclusion of older documents that are still timely. Other features unique to FIREBASE are the inclusion of: (1) digests of selected unpublished reports; (2) digests of nonprint media such as videotapes, motion pictures, and slide-tape programs; (3) a section on fire-related training items, including interagency and international training schedules, course announcements, and digests of courses, lesson plans, and other training items.

HOW YOU CAN USE IT

Here is how you can put FIREBASE into action:

1. Think carefully about the kinds of fire information you need. Think of key words that describe the specific subject, process, species, or equipment that you need information about.

2. Decide whether you want the information limited by geographic locations, species, years of publication, authors, or other delimiters.

3. Call or write the nearest Access Center (see locations below) and express your needs as specifically as you can.

That is all you need do. The Access Center operator will search the computer file and send the printout of citations and digests to you by mail, usually within 3 days.

Access Center locations are:

FIREBASE Operations Center
Boise Interagency Fire Center
3905 Vista Avenue
Boise, ID 83705
Telephone: (208) 384-9457
FTS: 554-9457

FIREBASE Access Center
Science Information Services
PSW Forest and Range Experiment Station
P.O. Box 245
Berkeley, CA 94701
Telephone: (415) 486-3688
FTS: 449-3688

FIREBASE Access Center
USDA Forest Service, S&PF
1720 Peachtree Road, NW
Atlanta, GA 30309
Telephone: (404) 881-3734
FTS: 257-3734

FIREBASE Access Center
U.S. Department of the Interior
Natural Resources Library
Research Services Branch
Washington, D.C. 20240
Telephone: (202) 343-3896
FTS: 343-3896

FIREBASE Access Center
USDA Forest Service
Forest Fire and Atmospheric Sciences Research
P.O. Box 2417
Washington, D.C. 20013
Telephone: (703) 235-8195
FTS: 235-8195

DEVELOPMENT

This first database of the RRTIS was developed by the Forest Service, the Bureau of Land Management, the Energy Research and Development Administration, and others, under the guidance of an interagency steering committee and the Forest Service Technical Information Office. FIREBASE was developed in the Fire in Multiple Use Management Research, Development, and Applications Program at the Northern Forest Fire Laboratory, Missoula, Montana. The Laboratory is a facility of the Intermountain Forest and Range Experiment Station. The development phase began in January 1974 and was completed October 1976.

In October 1976 the database was turned over to the Forest Service's Deputy Chief for State and Private Forestry. The Program is headquartered at the Boise Interagency Fire Center, Boise, Idaho. Douglas H. Baker is program manager, and Karen L. Eckels is assistant program manager.

Upon its transfer to Boise, FIREBASE began a 2-year operational test and evaluation to determine its cost effectiveness and utility to the fire community. Survival of the Program depends heavily upon user interest during the next 12 months.

A newly appointed Users' Representative Council will guide the program during the test period. Questions and comments about the database should be directed to the FIREBASE Operations Center at Boise, or to:

J. O. Baker, Chairman
FIREBASE Users' Representative Council
USDA Forest Service
Aviation and Fire Management Staff
P.O. Box 2417
Washington, D.C. 20013

CURRENT CONTENTS AND USAGE

FIREBASE is a growing database, with 3,635 items in the file as of July 15, 1977. Of these, 1,000 are undergoing final proofreading and correction, but all 3,635 items are available for use. We expect to add about 1,400 new items to the file each year.

Since October 1976 some 200 requests, about 30 of them from 12 countries other than the United States, have been filled by the Access Centers. The bulk of these requests have been handled by the Berkeley and Boise Centers. The Access Center at Atlanta and two in Washington, D.C., opened in May 1977.

Subject Matter Coverage

The major categories of information in this file are shown in table 1. All items are assigned one or more of these 20 broad-topic descriptors. The descriptors are shown here to give you a general idea of the subject-matter coverage to date.

Table 1.--Broad FIREBASE topic descriptors and number of items in the file relevant to each descriptor.

No.	Topic descriptor	No. of items 1/
1	Fire, fuel fundamentals	1,070
2	Experimental fires	168
3	Fire mgmt. analysis	308
4	Fire mgmt. economics	62
5	Fire mgmt. planning	75
6	Fire mgmt. training	106
7	Wilderness fire mgmt.	150
8	Fire prevention	363
9	Fire detection	147
10	Fire suppression	674
11	Fire behavior	169
12	Smoke	99
13	Fire histories	119
14	Fire effects	717
15	Fire statistics	119
16	Fire weather	400
17	Fire hazard	79
18	Fire-danger indexes	189
19	Fuel management	737
20	Prescribed fire	379

1/ Total number of items exceeds 3,635 because many items are assigned more than one topic descriptor.

Please note that, although it is possible to retrieve all items on any topic, only in rare cases would this benefit the requestor. This is because the topics are very broad and because some of the items contain information only indirectly applicable to the topic. The fire suppression topic alone includes information on all suppression techniques (rationale, practices, equipment, and technology), all tactics and operations (presuppression, dispatching, initial attack and mopup), and all aspects of chemical fire retardant research and application.

Therefore, the topic descriptors are used by Access Center operators only to isolate large blocks of general subjects. To help them narrow a search, they use more precise key word descriptors. This process usually results in a printout of only the items most pertinent to a user's specific request.

Time Span Coverage

The following tabulation lists the number of items in the file according to the decade of publication or release of the original items. While it is likely that selected older items will yet be added to the file, greatest gains will come from current information items.

Decade of publication or release	No. of items
1890	1
1900	1
1910	12
1920	27
1930	91
1940	120
1950	507
1960	1,299
1970	1,499
Unknown 1/	78
Total	3,635

1/ Publications not dated.

Geographic Coverage

Although the file contains fire-related items from 30 countries, the bulk is made up of information items originating in the United States. With the exceptions of southern California and Australia, which are represented by about 250 and 50 items, respectively, Mediterranean-climate regions are poorly represented in the file. The Mediterranean Basin countries are listed in the file's geographic index for 11 items only.

YOU CAN HELP

We hope that this symposium in general, and the preceding paragraph in particular, will stimulate workers in Mediterranean climates to contribute items to the FIREBASE file. The proceedings from this symposium will doubtless provide valuable additions to the file, but other useful papers and reports are also needed.

If you have fire-related information you feel should be shared with the international fire community, you are urged to send it to:

Ms. Karen L. Eckels
Assistant Program Manager
FIREBASE Operations Center
3905 Vista Avenue
Boise, Idaho 83705

English language items or items translated to English are preferred, but all items will be considered for inclusion. Those not already translated to English will be translated, as resources permit, before they are added to the file.

If you want an item you submit returned, designate it as "loan copy." If the item is already in the file, your copy will be returned immediately. If it is to be added to the file, processing may take several months.

A FINAL POINT

Although this paper has focused on the mechanics and status of one small database, the underlying theme and urgent need is "sharing," the sharing of international resource science and management technologies, philosophies, and ideas. We all have much to gain and can lose nothing through improved information sharing techniques, and that is what FIREBASE is all about.

ACKNOWLEDGMENTS

It is a pleasure to acknowledge the support of D. H. Baker and K. L. Eckels, current manager and assistant manager, respectively, of the FIREBASE program; the technical leadership and guidance provided during the project's development phase by Dr. R. Z. Callaham, M. B. O'Hara, T. B. Yerke, V. P. Aitro, and the Fire Information Steering Committee chaired by Dr. C. W. Philpot; and the administrative support of Dr. J. E. Lotan and W. C. Fischer of the Fire in Multiple Use Management RD&A Program.

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FIRE AND NUTRIENTS IN THE MANAGEMENT OF AUSTRALIAN VEGETATION[1/]

R. H. Groves[2/]

Abstract: The Australian distribution of three vegetation types - sclerophyll shrubland, mallee woodland and eucalypt forest - is described in relation to fire and soil nutrient status. Previous fire regimes in Australia are diverse; historically there is a similarity with western U.S.A. Some guidelines are formulated for the deliberate use of fire in managing nutrient-deficient land and its associated vegetation.

Key words: Sclerophyll shrubland, Mallee woodland, Eucalypt forest.

INTRODUCTION

The title of this review covers two themes which have attracted considerable attention over the 70 years of plant ecological research in Australia - namely, the roles of fire and of nutrients. Though the role of climatic factors, especially rainfall, is important for delimiting Australian vegetation on a continental scale, this scale has proved too great for most research, which has been regional in approach and execution. At this regional level, research on the roles of fire and nutrients has influenced the directions of plant ecology in Australia seemingly more than that on other, single factors.

Recognition of the role of fire can be traced back to a paper by Domin (1911), who attributed the demarcation of vine-scrubs from open (sclerophyll) forests to "... *the regular bush fire which kills all the scrub plants springing up on the border of the forest*" (Domin's italics). For 50 years from 1911, research on the fire factor was intermittent. Studies by Jarrett and Petrie (1929) and Gilbert (1959) on pyric succession in eucalypt forests, and Specht, Rayson and Jackman (1958) in sclerophyll shrubland, were noteworthy in two respects: firstly, they bridged the gap between Domin's initial observations and the greatly increased research effort on fire beginning in the 1960's; and secondly, and importantly, they set a high standard which has rarely been reached in the results of field studies published subsequently.

The other theme of my title is nutrients. The role of the edaphic factor in delimiting Australian vegetation types seems first to have been recognised by Cambage (1907) and re-iterated by his geologist-botanist colleague Andrews (1913, 1914, 1916). Significantly, they both resided in Sydney, the vegetation around which is such visible proof of the role of the edaphic factor (see, for example, Beadle 1962a). In early writings the concept of the edaphic factor included both soil physical and chemical relationships. But by the 1950's it had come to mean mainly a soil nutrient factor with the overwhelming emphasis in coastal Australia given to the low level of soil phosphate. This 'Sydney' tradition has been extensively supported by results of subsequent research in both the Sydney region and elsewhere in southern Australia.

This historical context of research on single factors of ecological importance in Australia is important to the assessment of the extent of the interaction between fire and nutrient deficiency. The implications of this

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[1/] Presented at the Symposium on Environmental Consequences of Fire and Fuel Management in Mediterranean Ecosystems, Palo Alto, Calif. Aug. 1-5, 1977.

[2/] CSIRO Division of Plant Industry, P.O. Box 1600, Canberra City, A.C.T. 2601, Australia.

interaction for management policies - past, present and future - will be discussed in relation to the dynamics of Australian vegetation types. Much of the material in the latter part of this review will be speculative because only recently has Australian plant ecological research evolved from the 'single factor' approach to consider interactions. Seddon (1974) pointed appropriately to this progression and to the influence of the systems approach in effecting the transition.

My approach to the subject will be to consider separately three vegetation types - shrubland, mallee woodland and eucalypt forest - in relation to the environmental consequences of fire and fuel management. All three types are evergreen and the leaves of the dominants are sclerophyllous. The discussion will be confined as much as possible to southern Australia because of its Mediterranean-type climate, to accord with the Symposium subject. Significant amounts of summer rainfall occur on the east coast so that only south-west Western Australia is typically Mediterranean in its climate, although the combined effects of rainfall distribution and temperature regimes may classify the climate of a large part of southern Australia as 'Mediterranean'

VEGETATION TYPES

Shrubland

Sclerophyll shrubland or 'heath' in Australia is defined as "a community consisting of sclerophyllous shrubs and chamaephytes, many with ericoid leaves, varying in height from 1 to 5 feet" (0.3 to 1.5 m) (Wood and Williams 1960). Its physiognomy is analagous to Californian chaparral, Mediterranean garrigue, north-western European heath and South African fynbos (macchia). The plant ecological effects of fire in this range of heathlands and related shrublands were reviewed recently by Gill and Groves (1978). In the same volume I reviewed the information at present available on nutrient cycling in this vegetation type, especially the effects of fire and/or grazing on the inputs and outputs of scarce nutrients such as phosphorus (Groves 1978). Both reviews, to which the reader is referred for detail, contain information on the sclerophyll shrublands of southern Australia. Vegetation with the same physiognomy may also occur in subalpine and alpine areas of south-eastern Australia (Costin 1954) but little is known of the nutrition or the responses to fire of these shrublands of more limited, upland distribution.

The distribution of lowland sclerophyll shrublands is shown in figure 1, from which it can be seen that this vegetation occurs in coastal regions having either a Mediterranean-type climate (south-western Australia) or a subtropical climate (eastern Queensland) or a mixture of the two. The only feature of the climate constant for the areas in which sclerophyll shrublands are found is that total annual rainfall is greater than about 400 mm, irrespective of the seasonality of that rainfall. All areas of shrubland shown on figure 1 are, however, characterised by acid, sandy soils which are extremely low in nutrients, especially phosphorus and nitrogen (Specht and Rayson 1957, Hannon 1958, Specht, Brownell and Hewitt 1961).

Groves (1978) concluded from the rather limited evidence available that the level of inputs of phosphorus to sclerophyll shrublands was low over the short term (5 to 15 years) and that there was a fair chance that, during such a time period, losses owing to fire and surface erosion from sandy soils may deplete this added level. If rains of high intensity follow summer firing of heathlands, as can often happen in eastern Australia, significant loss of ash and surface soil particles can occur and thus the nutrient status of the soil-plant system, already low, will be depleted still further, to an extent depending mainly on the frequency, intensity and seasonality of firing.

The status of other, more immobile elements such as calcium, will probably be affected less by firing as they are usually present at levels adequate for plant growth and because the accession of them may be greater, as in rainfall for example, in relation to losses (Groves 1978).

Fire is one of the most significant environmental factors affecting shrubland composition and productivity (Gill and Groves 1978). In Australia the interaction between fire and the nitrogen and sulphur status of sclerophyll shrublands seems especially important. In some shrubland areas low soil nitrogen and sulphur levels can limit substantially the growth of herbaceous communities of introduced species (Williams and Steinbergs 1958). It is also known, at least for *Calluna* shrublands of northern Europe (as reviewed by Gimingham 1972), that the level of these elements may be depleted considerably by losses as smoke, especially in fires of high intensity. Such losses may be made good by rainfall accession in coastal areas and by symbiotic fixation of nitrogen by root nodule-bearing species after fire. Some quantification of these processes seems essential before we can refine the level of management of Australian shrublands by a policy of planned firing.

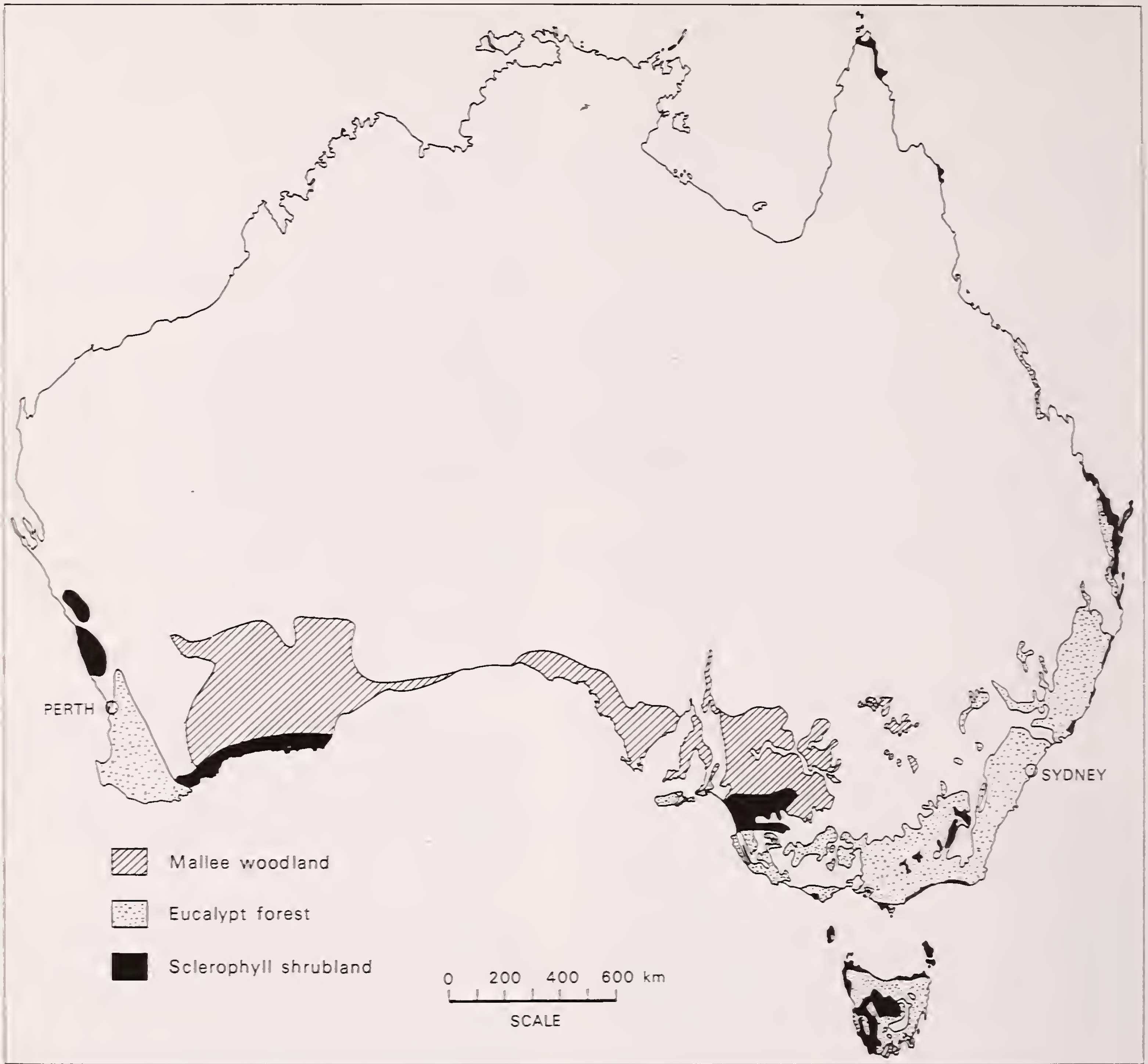

Figure 1 - Distribution of sclerophyll shrubland (heath), of mallee woodland, and of eucalypt forest in Australia (from Moore and Perry 1970).

Mallee Woodland

Mallee woodland is a vegetation type unique to southern Australia characterised by low (c. 2-8 m), eucalypt trees with many stems arising from a well-developed underground lignotuber. Although most *Eucalyptus* species possess a lignotuber (McArthur 1968), common usage of the term 'mallee' among Australian plant ecologists refers to vegetation dominated by trees with a well-developed lignotuber. The distribution in southern Australia of this

vegetation is shown in figure 1. It is termed 'open-scrub' by Specht (1970), though I prefer 'mallee'.

Development of a shrub and herb understorey to the eucalypt canopy varies regionally. For South Australia Specht (1972) described five understorey types, ranging from sclerophyll to semi-succulent shrubs to hemispherical hummocks of the grass *Triodia irritans*. In semi-arid areas (less than 400 mm average annual rainfall), the herbaceous understorey may be ephemeral and the shrub component sparse (Wood and Williams 1960). Thus, there is considerable diversity within this vegetation type and few generalisations are possible. Some eucalypts usually associated with forests (for example, *Eucalyptus baxteri, E. gummifera*) may assume a mallee form in some areas - a further complexity.

Parsons, (1968, 1969), Parsons and Specht (1967) and Parsons and Rowan (1968) indicated the importance of a number of edaphic factors, such as the nature of the topsoil (whether calcareous or siliceous), pH, levels of nitrogen, phosphorus, potassium and calcium, and also susceptibility to waterlogging and salinity, in affecting the physiological and ecological responses of some individual mallee eucalypts. The approach to these studies was largely autecological, but for a community so dominated by eucalypts this is not necessarily a deficiency.

Other recent studies (Holland 1968, 1969, Burrows 1976) concentrated on growth, productivity and nutrient cycling of the community. Burrows (1976) presented partial cycles for phosphorus and nitrogen in mallee vegetation of 2 ages, based on data on annual rainfall, productivity and nutrient distribution, and nutrient fluxes out of the canopy. Phosphorus and nitrogen pools were similar for both 15 and 50+ year old mallee communities.

There are fewer studies on the responses of mallee woodlands to fire. Eleven months after a fire Zimmer (1940) noted a large increase in the number of species, especially annual herbs. Changes in shoot biomass of mallee *(Eucalyptus incrassata)* - broombush *(Melaleuca uncinata)* vegetation were described by Specht (1966) up to 11 years from fire. Biomass reached a plateau at 10 to 15 years from fire. Relative to sclerophyll shrubland growing in the same area, mallee-broombrush showed an especially high level of calcium and sodium uptake. Apart from these two studies I can find no other information on the responses of mallee woodlands to fire, although large areas of this vegetation may be burnt, as for example in western New South Wales in 1974. In a vegetation characterised morphologically by a structure so well adapted to overcome stress, including fire (see Gill, this volume), it is a surprising deficiency. An experimental and quantitative study of the extent of the fire x nutrient interaction at the same site in central New South Wales as that for which Burrows (1976) has provided phosphorus and nitrogen cycles could be especially rewarding if instituted shortly.

Eucalypt Forest

Many of the 500 or so species of *Eucalyptus* endemic to Australia dominate forests of varying height and canopy classes to form what in this review are called eucalypt forests. They occur at all latitudes in both subtropical and temperate regions but are tallest (over 30 m) in those areas of south-eastern and south-western Australia where rainfall exceeds about 1000 mm per year. Their distribution is shown in figure 1. Understorey types range from low trees (> 8 m) and tall shrubs, to low shrubs (< 2 m) or tussock ('bunch') grasses. Because of the dominance by eucalypts, and sometimes by more than one species of eucalypt, such vegetation is always sclerophyllous but the understorey may not always be, especially at the wetter end of the spectrum.

Eucalypt forests have "flat crowns and bole usually greater in height than depth of crown; the crowns are continuous or nearly so" (Wood and Williams 1960), and are thus distinguished from woodlands which may also be dominated by eucalypts, usually but not always of different species. In moist situations in Tasmania and eastern Queensland tall eucalypt forest may be seral to closed forest (so-called temperate or tropical rainforest respectively) if protected from wildfire for long enough (up to 300 years - Gilbert 1959, Webb 1959).

While the distribution of eucalypts in Australia is largely controlled by rainfall within the annual rainfall zone of 600 mm to 1000+ mm, eucalypt forest generally occurs on soils of medium to low nutrient status. Local differences in the level of soil nutrients may lead to differences in composition of overstorey (for example, McColl 1969) and both over- and under-storey species (for example, Specht, Brownell and Hewitt 1961). Nutrients shown to be important for differentiation of forest species at the local level include phosphorus (Beadle 1954, 1962a), calcium (Moore 1959), and phosphorus and calcium (McColl 1969). The relative availability of soil phosphorus and aluminum among other factors, may even explain the differentiation between tree and mallee forms of the same species growing in the one climatic region, as Mullette (1976) showed for

Eucalyptus gummifera.

Wherever eucalypt forests occur in Australia they are fired at frequencies which vary from once every 300 years or so for some forests in south-eastern Australia dominated by *E. regnans* (Gilbert 1959) to annual burning of the grassy understorey in some tropical sclerophyll forests in northern Australia (Stocker 1966). Many eucalypts are adapted to withstand particular fire regimes because of resistant bark (Gill and Ashton 1968, Vines 1968), epicormic bud development on the bole following fire (Jacobs 1955), or the possession of lignotubers (Kerr 1925) at the base of the stem which are able to regenerate new stem tissue following fire. Species such as *E. regnans* which have none of these characteristics nevertheless are adapted to fire, but to a regime of a high intensity fire every 300 years or so. *Eucalyptus regnans* regenerates from seed given a bare forest floor and high light intensities to allow for successful seed germination and seedling tree growth. But a regime of one such fire followed by another within 20 years before the young trees have seeded, will eliminate the species from the site (Gill 1975). Thus the responses of eucalypts to fire are varied as are those of the range of understorey species which together comprise eucalypt forest communities.

To study adequately the ecological significance of the interaction between fire and nutrients requires detailed knowledge of nutrient cycling in a range of eucalypt forests followed by the imposition of firing treatments on those cycles. Results of such studies are not available even for one eucalypt forest, let alone a range of different forest types, though some effort is being made in this direction (J.L. Charley and B.N. Richards, personal communication, 1977). Guthrie (1976) reported on some aspects of cycling of calcium, magnesium, sodium and potassium in a mixed eucalypt forest in central Victoria in terms of the balance of both water and nutrients entering and leaving a closed catchment. He showed a positive balance for calcium and a negative one for magnesium. In general, however, results on the efficiency of nitrogen and phosphorus cycling in eucalypt forests may be much more significant to management than those for other such important nutrients as calcium.

Some aspects of phosphorus cycling in eucalypt forests have been investigated, but in isolation from fire. Attiwill (1964) quantified the levels of phosphorus, except those in the root system and soil, of a mature *E. obliqua* forest and concluded that the phosphorus cycle was characterised by internal redistribution from senescing to developing tissue, compared with the calcium cycle in the same community where the external cycle via the plant litter was more significant. Attiwill's conclusion is probably general but other sets of results for other sclerophyll forests are required. While the level of phosphorus in eucalypt litter is low (Hatch 1955, Ashton 1975, Attiwill 1964) the amount released when the litter is fired may be significant to phosphorus uptake in the long term.

In the early stages of pyric succession eucalypt regeneration is usually accompanied by regeneration of species with the ability to fix nitrogen symbiotically. The latter most commonly belong to the genera *Acacia, Casuarina* and *Macrozamia*. Halliday and Pate (1976) showed that the presence of the cycad *Macrozamia riedlei* contributed about 19 kg ha^{-1} yr^{-1} nitrogen to the *Eucalyptus-Banksia* sclerophyll woodland in which it occurred. The rate of fixation of atmospheric nitrogen by the luxuriant growth of *Acacia* spp. often following firing of eucalypt forest may be even higher, and should receive greater research attention in the future.

On the basis of the considerable information available on the effects of low nutrient supply on the distribution and growth of sclerophyll species, and some information on the responses of these three types of sclerophyll vegetation to fire, how can the level of management of such fire-prone vegetation be refined? For sclerophyll vegetation which, in Australia at least, is already deficient in nutrients, how may the planned use of fire be made compatible with minimising the chance of further loss of scarce nutrients? I shall attempt to answer these questions in the next section of this review. Because of the paucity of information on both nutrient cycling and on the ecological significance of the interaction between fire and nutrient availability, most of the answers will be tentative and unsubstantiated.

MANAGEMENT OF AUSTRALIAN VEGETATION

In prehominid Australia fires occurred naturally because of lightning strikes. The aborigines came to the Australian continent over 30,000 years ago during which time their hunting activities undoubtedly changed the prehominid fire regime, at least in some parts and probably in different ways in different regions. European colonization of the seaboard commenced almost 200 years ago, and of the hinterland soon after. For this 'colonial' period King (1963) commented on the changes in area and intensity of fires, but all such

efforts at historical generalisation underplay the diversity of fire regimes which probably still existed. As settlement spread, protection of the vegetation from fire was attempted, especially in areas of forested water catchments. Historically, this phase tends to match the era of fire protection in western U.S.A. This protection regime imposed upon the vegetation may have produced the serious wildfires rather than wildfire occurrence as such.

More recently, the protection phase of the history of the use of fire in Australia has given place to a policy of prescribed firing in forests aimed at reducing the level of flammable fuel on the forest floor, a policy which has been vigorously promulgated by its proponents (e.g. McArthur 1967) and equally vigorously opposed by its antagonists. Again, there are historical similarities, slightly displaced in time, with U.S. experience. It is still too early to say, however, if land managers in Australia are now entering the 'let burn' era presently existing for natural fires in some wilderness areas of the United States (Kilgore 1976). At the moment all we can say is that it is not yet readily accepted by managers of reserved land. No matter what the particular fire policy practised for a region there will be both desirable and undesirable consequences ecologically. Future management policies using fire must seek to maximise the desirable ecological consequences while still affording a high level of human protection. Herein lies the dilemma for the land manager.

We do not know what effect this diverse pattern of fire history has had on the nutrient economy of Australian plant communities. Probably, it has further decreased the levels of scarce nutrients which were already low because of parent rock composition (Beadle 1962b) and leaching over geologic time (Wild 1961, Ellis 1969). In south-eastern Australia fires of high intensity have not only been the sources of great economic losses (Stretton 1939) but may have deflected plant successions after fire (Jackson 1968) and have probably led to losses from ecosystems of elements such as phosphorus, nitrogen and sulphur. In a preliminary way, Harwood and Jackson (1975) showed that the extent of losses may be considerable. On the other hand, such losses may be balanced to varying extents by temporary changes in soil chemistry induced by high temperatures (Humphries 1966) or by a complex of soil ecological changes occurring locally as a so-called 'ash bed' effect (Renbuss, Chilvers and Pryor 1973).

The current practice of using prescribed fires of low intensity to reduce the flammability of forest understories and litter may have a quantitatively lesser effect in the short term on the relative sizes of nutrient pools than the high intensity fires which occur periodically. For example, Rowe and Hagel (1974) could find little change in nutrient content of surface soils after low intensity firing of the litter of a eucalypt forest in central Victoria. Some calcium, potassium, sodium and sulphur was able to be leached out from post-burn soils if leaching occurred soon after the burn. The cumulative ecological effects of fires of low intensities repeated every 5 to 7 years may be expressed more in the deflection of plant successions from the less flammable herbaceous understories characteristic of forests prior to European settlement (King 1963) in favour of shrubby sclerophyll species. Many of the latter group have the ability to fix nitrogen symbiotically but the effectiveness of fixation in the field is not known. It will depend on such factors as the phosphorus and trace element status of the soil, moisture availability etc.

Some general guidelines may be formulated in relation to the use of fire in the management of the three types of Australian vegetation I have described. They are proposed primarily to stimulate further research as well as to influence the decisions of land managers. These include:

1. For plant communities dominated by species regenerating from underground rootstocks (sclerophyll shrublands and mallee) the firing frequency to ensure the maximal level of species survival may be the one approximating the time at which shoot biomass reaches a plateau. For sclerophyll shrubland in southern Australia I have suggested this interval between fires may be from 10 to 15 years (Groves 1968). Such a frequency of firing should ensure that root reserves are maintained - they probably will be depleted if firing is more frequent than this interval. For some mallee vegetation such a frequency may be at least 30 years (Burrows 1976).

2. Initially following disturbance there may be a rapid uptake of nutrients after which the community requirement (at least for mobile elements) is largely met by recycling. Burrows (1976) suggested that this may be so for mallee vegetation, and it may be a general result for Australian sclerophyll communities, at least for phosphorus (Attiwill 1964).

3. The low stature of some sclerophyll shrublands protected from fire up to 20 years may gradually change as tall sclerophyll shrubs of genera such as *Banksia*, *Leptospermum* and *Eucalyptus* (Jones, Groves and Specht 1969) and *Hakea* become more prominent. A regime of two

fires within the time period from germination to first seeding (about 3 years or more for these genera) may restore the former structure of the community and even eliminate the taller-growing species from the area, as Burrell (1968) postulated for *Leptospermum laevigatum* and Gill and Groves (1978) for *Hakea teretifolia*. Siddiqi *et al*. (1976) concluded that firing as frequently as every two years or so could eliminate these tall shrub species which re-generate solely from seedlings, but such a regime seemed to be essential for the continued survival of some herbaceous and low shrub species, e.g. *Banksia aspleniifolia* which may regenerate both by root sprouting and as seedlings.

4. For all sclerophyll communities on sloping land firing preferably should be in autumn when rains are generally of lower intensity and hence the chances of soil particle movement are less. The loss of nutrients as soil particles may be a major source of loss of phosphorus, for example, to such nutrient-deficient communities. Firing in autumn also means that the peak of leaf fall (in summer in these communities) has passed which may be beneficial in a fire protection sense.

5. In some eucalypt forests and especially in subalpine mallee woodlands protection of the community from fire for a period of 30 or more years may lead to a reduced incidence of flammable leguminous shrubs in the understorey (because their life cycle is only about this length) and their replacement by less flammable grasses and herbs. Research on this approach to vegetation management is currently under way in one region (R.B. Good, personal communication, 1977). Alternatively, a regime of one high intensity fire and several subsequent low intensity fires 2 to 3 years apart may also change the understorey from shrubby and flammable to grassy and less flammable species.

6. In terms of the economy of scarce nutrients such as phosphorus some artificial addition may be foreseen for forests intensively managed for cellulose production. Additions of exogenous nitrogen may also be feasible (and economic?) for those forests in which species able to fix nitrogen symbiotically are relatively absent from the understorey. This possibility of course does not apply to areas significant for nature conservation, as Heddle and Specht (1975) showed that, for south-eastern South Australia at least, nutrient addition in association with fairly frequent firing could change the floristic composition of a shrubland from predominantly sclerophyll to predominantly herbaceous species.

This review has stressed the role of fire regimes in potentially altering understorey composition which may have an important role in nutrient flow in the whole plant community. For a eucalypt forest, Ashton (1975) showed a high level of calcium in litter from the under-storey species *Pomaderris aspera*, which may be analagous to the role of *Cornus florida* acting as a 'nutrient pump' in calcium cycling in eastern U.S. deciduous forests described by Thomas (1969). A policy of control burning may in the long term exacerbate an already nutrient-deficient situation.

ACKNOWLEDGMENTS

It is a pleasure to acknowledge : the invitation of Dr. H.A. Mooney to write this review; the comments on a draft of this review by several colleagues - Dr. W.H. Burrows, Dr. J.L. Charley, Dr. A.M. Gill, Mr. R.B. Good and Dr. R.J. Raison; and the various funding agencies who made its verbal presentation possible.

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ECOLOGY OF CAPE FYNBOS IN RELATION TO FIRE[1/]

F.J. Kruger[2/]

Abstract: Conservation of Cape fynbos (sclerophyllous shrublands), a biome-type with unique biogeographic features, includes habitat management by means of prescribed burning. This practice is based principally on the observation that community diversity is dependent on periodic fire. These communities respond much like those of other Mediterranean type and related ecosystems, but are possibly unique in that most include a comprehensive range of responses. Initial observations confirm the obvious view that community response to fire regime varies according to community type, and season and frequency of burning: the nature of these responses and the underlying factors responsible for their manifestation require further inquiry, particularly to permit more refined management.
Key words: Mediterranean ecosystems, sclerophyllous shrublands, biogeography, succession, conservation.

INTRODUCTION

Fynbos is the broad category of sclerophyllous shrublands which dominate the vegetation in the region of the Cape Floral Kingdom. Taylor (1977) has identified the following features peculiar to or characteristic of these formations: (a) the invariable presence of the family Restionaceae (b) two normally dominant (or co-dominant) physiognomic elements, the restioid -- wiry aphyllous hemicryptophytes, mainly of the Restionaceae -- and the ericoid element, which comprises dwarf and low evergreen shrubs with small, hard, narrow, rolled leaves (Ericaceae, *Phylica*, *Metalasia*, *Stoebe*, and others). Another typical and often dominant growth form (not invariably present) is the tall broad-sclerophyllous shrub -- Taylor's proteoid element -- which normally comprises certain members of the Proteaceae, including *Protea* itself. Native trees are absent or rare. Communities are very rich in plant species (table 4) and are probably the richest shrubland communities in the world. Adamson (1931) and Acocks (1975) have emphasized the high beta diversity in community dominants (which the former called "lack of single-species dominance").

Three major types of fynbos are normally recognized, principally on habitat differences, and these are Coastal (Acocks Veld Type 47), Mountain (most of Veld Types 69 and 70), and Arid Fynbos (Veld Types 69 and 70 in regions of less than about 350-400 mm rainfall yr^{-1}).

Acocks (1975) lists 25 plant families whose members occur ".. as dominants in all the variations of fynbos...". Consistently dominant families are Restionaceae, Cyperaceae, Proteaceae and Ericaceae, although members of others such as Bruniaceae and Asteraceae may dominate in special habitats.

[1/] Presented at the Symposium on Environmental Consequences of Fire and Fuel Management in Mediterranean Ecosystems, Palo Alto, Calif. Aug. 1-5, 1977.

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Table 1 -- Examples of endemism and near-endemism in plant taxa of the Cape Floral Kingdom*

Family	Genera	No. of Species	Comments
Bruniaceae**	*Brunia*, *Berzelia* and ten others	98	
Penaeaceae**	*Penaea* and 5 others	13	
Stilbaceae**	*Stilbe* and 4 others	15	
Grubbiaceae**	*Grubbia*	3	
Roridulaceae**	*Roridula*	2	
Geissolomataceae**	*Geissoloma*	1	
Retziaceae**	*Retzia*	1	
Ericaceae	*Erica* and 22 others: 19 endemic	780	97 per cent of species endemic
Proteaceae (Proteoideae)	*Protea*, *Leucadendron* and 11 others: 9 endemic	348	95 per cent of species endemic
Restionaceae	*Restio*, *Thamnochortus* and 10 others: 9 endemic***	193	98 per cent of S.A. species endemic
Rutaceae (Diosmeae)	*Agathosma* and 11 other endemic genera	c.200	
Fabaceae	*Aspalathus*+	258	
Rhamnaceae	*Phylica*+	149	
Polygalaceae	*Muraltia*+	115	
Rosaceae	*Cliffortia*+	108	
Geraniaceae	*Pelargonium*+	80	

* Compiled from Dyer (1975, 1976), Oliver (1977) and Taylor (1977).

** Families endemic to Cape Floral Kingdom: they are confined to fynbos.

*** Cutler (1972) maintains that the family is incorrectly classified and that there are no genera common to South Africa and Australia.

+. Genera with more than 90 per cent of species confined to the Cape Floral Kingdom.

The flora of the Kingdom is distinguished by certain key phytogeographic features (Oliver 1977, Taylor 1977): (a) marked endemism in certain taxa and pronounced regional concentration of species in typical, but not entirely endemic genera (table 1); many endemics have a very restricted range (see H.C. Taylor, these proceedings); (b) predominance of certain families and genera (table 2); (c) possibly the richest floras in the world; and (d) large changes in the floras from one landscape to the next (delta diversity). These features are most pronounced in the flora of the fynbos zone.

Other plant formation categories in the region of the Cape Floral Kingdom include two types of low narrow-sclerophyllous shrubland dominated by members of the Asteraceae (e.g. *Eriocephalus* and *Elytropappus*); these are Mountain Renosterveld and Coastal Renosterveld -- Acocks' (1975) Veld Types 43 and 46. Another formation is the southern phase of Strandveld (Acocks Veld Type 34), a dense broad-sclerophyllous scrub with many spiny species and frequent succulents. Both of these categories, described in detail by Taylor (1977), lack the typical features of fynbos.

Evergreen mesophyll forests are present but confined to ravines and similarly sheltered sites, covering a small fraction of the land area.

The fynbos ecosystem is actively conserved, because of its scientific, economic and aesthetic values, and this aspect will be examined further by Bands (these proceedings). Management of fynbos plant communities by means of prescri-

Table 2 -- Prominent families and genera in fynbos floras.

Family*	Mean Rank	Genus**	Mean Rank
Asteraceae	1.0	Erica	1.0
Ericaceae	4.0	Restio	2.7
Fabaceae	4.0	Ficinia	4.3
Iridaceae	4.3	Senecio	5.3
Cyperaceae	4.8	Cliffortia	6.3
Restionaceae	5.0	Aspalathus	6.7
Orchidaceae	6.5	Tetraria	7.3
Poaceae	6.5	Helichrysum	8.0
Proteaceae	10.0	Pentaschistis	9.7
Campanulaceae (sensu lato)	10.3	Disa	10.7

* Compiled from floras for the Cape Hangklip area (Boucher 1977), Jakkalsrivier experimental catchment (Kruger 1974), Cape of Good Hope Nature Reserve (H.C. Taylor, unpubl.), and Jonkershoek State Forest (Dept. of Forestry, unpubl.)

** Compiled from the same floras with the exception of the Cape of Good Hope Nature Reserve.

bed burning, to maximise water supplies, for habitat manipulation, and for fire and weed control, is central to conservation of these ecosystems. I propose to examine the ecology of the natural fynbos communities in relation to fire, to analyse the assumptions and hypotheses underlying present management, and to suggest certain critical lines of inquiry necessary for successful conservation. This analysis is preceded by a general descriptive account of the ecosystem as a framework for what follows.

NATURE OF THE FYNBOS ECOSYSTEM

Physical Environment

Taylor (1977) and Kruger (1978a) present reviews of the physical environment of the fynbos ecosystem. The vegetation occurs in the region of the Cape Folded Belt, between about latitudes 31° and 35° south and longitudes 18° and 27° east. This region is dominated by anticlinal ridges of quartzites, with moderate elevations (maximum of 2 325 m) but pronounced local relief (1 500 m in 2.9 km). Granite underlies the foothills in parts. The sub-parallel mountain ranges are separated by broad intermont valleys, and are flanked to the south by a more or less dissected peneplain. Shales are normally the underlying rocks in these lowlands. Cainozoic limestones and sands occur in a zone of varying width along the coast.

The mountains of this zone are oriented roughly parallel with the coastline: their orientation and relief, the warm Agulhas current to the south and the cold Benguela current to the west interact with the general weather systems of these latitudes to produce a variety of climates. This is illustrated in table 3. The most notable gradients are between typical winter rainfall regimes in the west and all-year patterns in the east, and from arid to perhumid climates (rainfall up to 3 330 mm yr^{-1}). Most stations are free of frost, except in depressions in interior valleys and on high-altitude plateaus and basins -- De Keur, on a subsummit plateau in the Koue Bokkeveld mountains, has an average of 25 frost-days per year.

Coastal and mountain stations especially are very windy. Summer weather is dominated by persistent strong anticyclonic south-easters, which cause acute fire control problems in the west, while winter weather is characterized by periodic gale-force cyclonic north-westers. Berg winds, analogous to Santa Anas, often precede advancing frontal systems; many fires in the southern and eastern regions occur during this type of weather.

The fynbos climates do not all comply with Aschmann's (1973) definition of the Mediterranean type, some being too dry and some too wet, and others have too low a proportion of winter rainfall.

Where fynbos occurs on coastal forelands soils are sometimes neutral to alkaline. In the mountains and foothills soils are all acid (pH down to 3.5) and podzols and podzolic profiles are the rule. Profiles normally comprise structureless sands or sandy loams, with dark grey-brown A-horizons (although organic A's occur in some wet habitats). Mountain landscapes typically have the normal A-horizon on hard rock, weathered rock or stony drift material. Where weathering is relatively deep or where

Table 3 -- Climate statistics for a range of fynbos stations

Station	Lat. S	Long. E	Elev. (m)	Mean annual temp. (°C)	Annual temp. range (°C)	Rainfall (mm)	Per-cent winter rain	EP*
Cape Columbine	32°50'	17°51'	6	15.2	4.3	229	82	2.2
Danger Pt.	34°37'	19°18'	28	16.1	5.6	544	68	5.0
Port Elizabeth	33°59'	25°36'	58	17.2	7.9	576	54	4.9
Citrusdal	32°34'	18°59'	250	18.9	12.6	333	89	3.0
Cape Town (Roy. Obs.)	33°56'	18°29'	12	17.4	8.8	672	78	5.7
Jonkershoek	33°59'	18°57'	282	16.1	10.0	1273	77	12.3
De Keur	32°58'	19°18'	955	14.0	12.0	572	82	6.4
Table Mt. House	33°59'	18°24'	761	12.9	7.9	1780	74	19.1
Tygerhoek	34°09'	19°54'	168	16.8	10.6	449	62	4.0
Deepwalls	33°57'	23°10'	519	15.6	6.6	1214	45	10.9
Grahamstown	33°18'	26°32'	539	16.4	9.0	697	38	5.9

* EP = effective precipitation (Bailey 1958).

material accumulates (profiles deeper than about 50 cm), greater differentiation has occurred and eluvial horizons with or without ferrihumic B-horizons are the rule in the cooler, humid southern ecosystems but yellowish-brown or reddish B-horizons underly the A on shales and granites and in warm, dry zones. Soils on quartzites are very infertile, with P contents ranging from about 1 to 4 p.p.m. and total N from 0.05 to 0.20 per cent; on shales and granites, these levels are higher, up to 40 p.p.m. and about 0.1 to 0.4 per cent respectively. Base saturation levels are around 20 to 40 per cent or lower in all cases.

These soils are highly porous and resistant to erosion. No or very little surface runoff occurs even in the most intense rain (up to about 60 mm hr^{-1} on a 15 minute time module -- Wicht et al. 1969). The combination of steep mountain physiography, climate and porous soils results in typically flashy stream hydrographs (Wicht 1943) and runoff: rainfall ratios of up to 50 per cent and higher (Wicht 1971), but the porous mantle and cracked and jointed rock strata serve as aquifers which maintain flow year-round even in small catchments.

Fynbos communities occur generally in the zone described, but are replaced by Renosterbosveld types on quartzites where rainfall is less than about 200 to 250 mm yr^{-1} and on shales and granites where it is less than about 550 to 650 mm yr^{-1}. Except on some coastal sites, fynbos does not survive on base-saturated soils. There are abrupt transitions from fynbos to forest which are not associated with obvious climatic or soil changes, and which can seldom be ascribed to burning history or other persistent disturbance. East of about 24°, with increasing summer rainfall, grasses steadily gain importance in fynbos until the typical physiognomic elements become unstable components of the community, easily eliminated by, for example, a change in fire regime (cf Trollope 1971).

Plant community structure

A wide range of structural formations is found in the fynbos zone, from low communities dominated by Restionaceae or Cyperaceae or both, to tall dense broad-sclerophyllous scrub. Taylor (1977) has described the manner in which these formations are loosely segregated in zones, i.e. a proteoid zone of the foothills and lower slopes, in which communities have an upper layer of tall broad-sclerophylls, especially Proteaceae, and two other layers, and an ericoid-restioid zone at upper elevations, where the broad-sclerophyllous shrubs are sparse or absent. At uppermost or in otherwise extreme sites, all shrubs may be sparse. This

Table 4 -- Summary of community data for a range of fynbos structural formations[a]

Formations	Openscrub		Tall shrub-land with heath		Low open-heath		Low graminoid-heath		Low closed-herbland	
Elevation (m)	490		285		820		930		840	
Rainfall (mm)	1600		1600		950		950		950	
Total canopy cover (%)	95-100		95		80		95		95	
Total plant species	72		126		52		71		31	
	No. of spp.	R.I.[b]	No. of spp.	R.I.	No. of spp.	R.I.	No. of spp.	R.I.	No. of spp.	R.I.
Tall shrubs(2m, evergreen)	2*	48.0	1	36.8	0	0	0	0	0	0
Low and mid-ht shrubs (0,25 - 2 m)										
Evergreen	25	46,5	45	34.8	17*	60.7	21*	48.8	5	2.7
Deciduous	2	+	3	3.6	0	0.0	0	0	0	0
Shrub and tree sub-total	29	94.5	49	75.2	17	60.7	21	48.8	5	2.7
Dwarf shrubs (evergreen)	7	+	10	0.6	4	+	13	+	2	0.4
Graminoid herbs	13	4.0	17	19.8	23	38.0	22	45.7	13	90.3
Geophytes	18	+	34	1.4	7	0.3	10	4.5	9	5.9
Other herbacious perennials	3	+	7	0.4	1	+	5	0.5	2	+
Herbaceous perennials sub-total	34	4.0	58	21.6	31	38.3	37	50.7	24	96.2
Annuals	1	+	7	+	0	0	0	0	0	0
Succulent shrubs	0	0	2	+	0	0	0	0	0	0
Vines	1	+	0	0	0	0	0	0	0	0

a. Compiled from data in Kruger (1978a). All data for 20 x 50m plots.

b. R.I. = relative importance as percentage of total crown volume (sum of products of height and cover for each species). '+' denotes trace.

'*' Synusiae dominated by seed-regenerating shrubs.

pattern is rather diffuse and often inconsistent. Cutting across the zones, for example, are a series of narrow-sclerophyllous scrub communities on the phreatic habitats of bogs and streams.

With the exception of plant communities in extreme habitats (for example, where soils are alternatively waterlogged and droughted), alpha diversity is consistently high (table 4) and some record figures are 83 species on 50 m^2 and 121 species on 100 m^2 (H.C. Taylor 1977; and these proceedings).

Table 4 summarises data on the structure of a range of fynbos communities. An important feature is the great diversity of perennial herbs in all communities. Although the relative importance of herbs may vary considerably they are a significant component of all communities, with a biomass ranging from about 2 000 to 10 000 kg ha^{-1}, even in old stands. This characteristic distinguishes fynbos communities from Mediterranean and New World analogues, and allies them with Australian heaths (Kruger 1977).

Incidence of fire

This subject is examined elsewhere in greater detail (Bands, these proceedings) but certain points should be emphasized. It is difficult to determine a "natural" fire frequency for this vegetation, but by inference this appears to be approximately between six and thirty years, since fire more frequent than that would eliminate some extant plant species, and vegetation older than forty to fifty years is rarely encountered, even where areas are deliberately protected (Kruger 1978a). There is a physical limit to fire frequency, since under normal conditions sufficient fuel for another fire takes about four years to accumulate. The actual frequency at which fire occurs in a given community is likely to vary between these hypothetical limits, as a function of ignition probability and of long-term weather patterns. Open fynbos communities of sub-arid and arid climates would, of course, burn less often.

The fire season must reflect the dominant influence of local climate and, predictably, most fynbos fires occur in summer in the west, but in the south most occur in winter, with a smaller peak in summer (le Roux 1969). However, although frequency distributions of fires do show fire seasons, these are not well defined. Older communities contain considerable quantities of fine fuel, much of which is cured, so that the fuel bed dries quickly, and fires are possible within days or hours after rain, in any season.

Finally, though fynbos fires are fairly intense (fires of intensity greater than 2 500 kW m^{-1} appear to be regular) they are apparently not as intense as most of those in mature chaparral, since fuel particles of diameter greater than about 6 mm are usually not burnt, ash-beds are rare or small, and structure of surface soil is retained. There is no evidence of marked hydrophobic effects on the soil.

SOME ASPECTS OF COMMUNITY FUNCTION

Periodicity

Like that of other vegetation in Mediterranean-type and related ecosystems (e.g. Mooney et al. 1977; Specht and Rayson 1957) the phenology of fynbos is complex and probably more so than in its analogues (cf. Kruger 1978b). Most species bloom in spring, but relatively many species flower at any time of year. Dominant tall shrubs tend to flower in winter or early spring. Time of shoot growth varies considerably among species, but time of growth tends to correlate with life- or growth-form. Thus, most herbs tend to grow in the interval from early winter through to the end of spring or into early summer, whereas shrubs tend to grow in the seasons of spring and summer. Among herbs, however, there are roughly two classes, those which initiate growth in early winter (normally geophytes), and those which grow from early spring through to summer (mainly graminoid hemicryptophytes). Similarly, among shrubs, some species produce new shoots and foliage in spring, while, at the other extreme, a number do so only in mid- to late summer. Others are intermediate, and some have bimodal rhythms.

Levyns (1929) has noted two categories with respect to time of seed-shed, i.e. winter seed-shedders and summer seed-shedders.

Species traits and responses to fire

Survival of fires

Species resistant to scorching -- Individuals of a few species of erect shrubs survive fire with all or most of their crowns intact while those of others around them are killed or obliged to resprout. In some cases, shoots and foliage are protected possibly by the shape of the crown, which apparently deflects the heat of the fire (*Protea laurifolia* Thunb., *Leucospermum conocarpodendron* (L.) Buek.), while cambium is protected by thick bark. Some prostrate shrubs, such as *Protea effusa* E. Mey. ex Meisn. and *Leucadendron glaberrimum* (Schltr.) Compton, also survive, although the perimeters of their crowns may be scorched. These species do not have the capacity for vegetative reproduction, a proportion of each population is killed in every fire, and populations consist of a series of even-aged sub-populations.

Species reliant on seed reproduction -- Species that rely entirely on seed for survival are found mainly among shrubs (trees are almost exclusively resprouters). Some hemicryptophytes (e.g. *Chondropetalum hookeranum* (Mast.) Pillans, Restionaceae, and *Ehrharta ramosa* Thunb., Poaceae) are killed by fire, so that, with the normal handful of annuals, there is also a small variety of herbs which return through germination. Thus, although fynbos floras are dominated by species which resprout, there is a significant proportion of reseeders (Michell 1922, Wicht 1945, Van der Merwe 1966; see table 5).

Various strategies which serve to enhance survival of fire through seed may be found among reseeders, including serotiny. In *Leucadendron*, 49 of 90 species retain seed in cone-like fruiting heads for some time (Williams 1972) -- up to at least 8 years in some species -- and a similar habit is found among many species of *Protea*. Here seed is released when the plant or the organ dies, as after fire. Other species, in Proteaceae and other families, release seed or fruit on ripening, and these have hard testas or pericarps which promote dormancy and longevity (Van Staden 1966; Williams 1972) -- there is circumstantial evidence that this seed can remain viable on or in the soil for about 15 years or longer (Boucher and McCann 1975; Rourke 1976). Many species, as in Ericaceae and Asteraceae, produce a superabundance of small, short-lived seeds (Levyns 1935a).

Vegetative regeneration -- The full array of vegetative regeneration modes in mediterranean type fire environments is found also in fynbos communities (examples in Michell 1922, Wicht 1945, Martin 1966, and Van der Merwe 1966). It includes the following (a) resprouting from dormant buds in the stem, in a few species like *Protea arborea* Houtt., *Maytenus oleoides* (Lam.) Loes. and *Heeria argentea* (E. Mey.) O. Kuntze; (b) resprouting from dormant buds in lignotubers of similar organs at or below the soil surface, which is perhaps the most common mode among shrubs and is associated with a typical, multistemmed growth form like dwarf Australian malee; (c) resprouting from rhizomes at or near the soil surface, as in most perennial graminoid herbs, and (d) resprouting from buds on underground storage organs (geophytes).

Reproductive responses

Many species exhibit pronounced positive reproductive responses to fire, usually through increased flowering but sometimes through enhanced vegetative reproduction (as in *Watsonia pyramidata* (Andr.) Stapf. -- see below -- and *Cliffortia linearifolia* Eckl. + Zeyh., Martin 1966). The degree of response ranges from apparent complete reliance on periodic fire for reproduction through to indirect response in shrubs, resulting from increased vigour following fire. In some instances, fire may induce flowering much earlier than normal (e.g. *Asparagus* sp. - Michell 1922).

Some examples of reproductive responses are examined below. There is evidence that the nature and intensity of the responses depend partly on the season of the burn.

Juvenile periods

The time required for plants to reach reproductive maturity after regeneration following fire varies from about one to 10 years. Individuals which resprout often flower within 12 months, and this includes some shrub species, though others may require up to 24 months (Michell 1922; Martin 1966). Primary juvenile periods, at least among shrubs, are more variable but most species reach reproductive maturity within eight years after germination (Kruger 1978a). Some species are precocious, as in *Anthosper-*

Table 5 -- Two fynbos floras classified by Raunkiaer life-form and mode of regeneration after fire.

Life-form	Swartboskloof*		Jakkalsrivier**	
	No. of spp. in class		No. of spp. in class	
	Vegetative regen.	Regen. from seed only	Vegetative regen.	Regen. from seed only
Phanerophyte	84	67	43	110
Chamaephyte	76	63	33	50
Hemicryptophyte	70	1	128	11
Geophyte	67	0	111	0
Therophyte	0	16	0	7
Unclassified	1	3	6	9
Total	298	150	321	187

*. From Van der Merwe (1966), **. Dept. of Forestry, unpubl.

mum aethiopicum L., reported flowering in the second year (Martin 1966), and Erica mauretanica L., flowering 30 months after fire (Michell 1922). Van der Merwe (1966) reports that some Protea repens L. individuals flowered in the third year. There is no realistic survey of primary juvenile periods, but there is evidence that the periods are influenced by habitat (Kruger 1978a) and one intuitively expects longer juvenile periods in drier habitats, for example.

Features of life-cycles of fynbos plants in relation to fire

There are no comprehensive studies on the life-cycles of representative fynbos species which would serve to illustrate possible species adaptations to fire, but information assembled mainly from unpublished sources provide a partial but useful picture. This shows that some species have fire adaptations, although most are probably pre-adapted.

Herbs whose responses are most often noted are the geophytic species. The extreme instance is the so-called "fire-lily"type, geophytes which appear in the sexual phase only in the year after fire. This includes various species of Amaryllidaceae, Iridaceae and Orchidaceae (Michell 1922, Hall 1959, Levyns 1966, Martin 1966). Hall (loc. cit.) showed that the incidence of geophytic Orchidaceae was strongly associated with recent fire; tagged samples of 10 species were all most abundant and active in the first one to four spring seasons after a burn, and virtually absent thereafter.

Some information on Watsonia pyramidata (Kruger unpublished) illustrates geophyte life-cycles and responses to fire. In this species, corm-discs are highly resistant to decay and remain in chronological sequence in the soil. Vegetative reproduction occurs when a ramet flowers: two new corms are almost invariably produced. It is therefore possible to excavate clones and examine their genealogy with some accuracy. Clones have a great longevity, several older than a century being found in random samples. Individual ramets are also long-lived, with a maximum observed age (before first flowering and clonal reproduction) of about 35 years. In unburnt populations, about five per cent of all ramets flower annually. If burnt in autumn (and possibly also in late summer), populations respond strongly, at least half of all ramets producing inflorescences. In populations burnt in spring, the number of plants flowering remains the same as that in unburnt vegetation or is slightly depressed. Since each inflorescence produces about 700 seeds, and since flowering induces vegetative reproduction fires in the "right" season obviously

have an enormous impact on Watsonia populations. Seedlings germinate freely in the following winter and spring, and contractile roots draw the new corm an average of 2.6 cm below the soil surface within 12 months; corms apparently grow for 4 to 8 years before first flowering. Thus we see that the species is well equipped to overcome unfavourable conditions, having the longevity to survive long intervals between events that produce suitable conditions for reproduction, and the capacity for pronounced response when suitable conditions obtain. Contractile roots ensure burial and good protection of the perennating bud against climate, predators and fire.

Shrubs adopt a wide variety of strategies and it is possible to note only a few here. There is little information on short-lived opportunistic shrubs which are often conspicuous after fire, disappearing thereafter (Adamson 1935, Van der Merwe 1966). Some have hard seed (like Aspalathus spp., including A. chenopoda L., and Chrysanthemoides monilifera (L.) T. Norl.) but many, especially the Asteraceae such as Euryops abrotanifolius (L.) DC. and Othonna quinquedentata Thunb., have small seed which are normally taken to be short-lived.

Protea repens and some allied species serve as examples of reseeding shrubs with longer life-cycles. P. repens itself is easily killed by fire but seeds germinate readily and there is usually little mortality among young plants. Populations require about four to eight years to reach reproductivity maturity (Jordaan 1949, Van der Merwe 1966), and a reasonable supply of viable seed is retained in serotinous capitula. In a 19-year-old stand at Jonkershoek, for example, all plants carried capitula two years old and older, and most had retained seed for at least four years. Lombaard (1971) has shown, in stands about ten to twelve years old, that current seed production amounted to about 900 to 1300 seed per shrub, of which about nine per cent was viable. Jordaan (1949) has drawn attention to the significance of the length of the juvenile period in determining whether or not the species would survive a given fire regime, and suggested on the grounds of embryology and phenology, that populations were liable to extinction if burnt during the period July to December, less so if burnt in April to June, but would regenerate in the period January to March because ripe seed was freely available only in that season. Later (1965) he showed that the species had been eliminated from Paarlberg by a June burn. His observation seems to have limited generality, since P. repens elsewhere survives winter burns because of serotiny, but he correctly drew attention to important interactions between fire regime and phenology.

Dominant seed regenerating shrubs reach ages of about 20 to 50 years, low shrubs such as Erica species having on the whole, shorter life-spans than tall shrubs. There is little or no establishment of young plants in vigorous stands, but some seed regeneration occurs when adults begin to die out.

The only species of sprouting shrub about which there is some information is Protea arborea (Haynes 1976). This species does not have serotinous capitula, but flowering and seed release occur somewhat irregularly through the seasons and germinative reproduction is usually abundand after fire and rare at other times. Young plants soon develop lignotubers; in the nursery, this occurs within 12 months after germination. These plants seldom reach maturity before being burnt for the first time, upon which they adopt a low, multistemmed habit. This habit is seemingly retained for many years until one of the shoots gains dominance and the plant takes on the form of an erect if crooked shrub, attains maturity and grows in height. In this stage, individuals are able to resprout from epicormic buds in the branches and stem or from the base, with nearly 100 per cent survival of even the most intense fires.

Succession after fire

Development of fynbos communities after fire must vary considerably with vegetation structure and the environmental variables that control it. For example, Levyns (1935b) describes an unusual succession in transitional sclerophyllous scrub where each of the first three years saw dominance by one or a few reseeding species, each of which declined thereafter: a germinative species of Aspalathus dominated in the fifth year, but this was likely to decline and be replaced by Elytropappus rhinocerotis Less., a longer-lived shrub in the Asteraceae.

However, field observation and information in Michell (1922), Levyns (1929), Adamson (1935), Wicht (1948), Martin (1966) and Taylor (1969) indicate that most fynbos communities follow a essentially similar course of succession after fire. The major features abstracted from these sources are outlined below.

Immediate post-fire phase -- Although fire intensities in fynbos range widely. burns are seldom so intense as to kill species that resprout. Since hemicryptophytes are important in most communities, initial recovery is rapid. Regeneration of all or most species occurs within the first twelve months after fire. Sprouting species, especially hemicryptophytes, appear within days or weeks at most, and some are able in this period to flower and set seed. Fire-lilies and almost all annuals reproduce only in this interval.

Some animals concentrate on vegetation because food is most accessible now (Francolinus africanus Stephens, feeding on corms of Iridaceae) or is most palatable (especially for antelope, like Pelea capreolus Forster). Levyns (1929) has noted heavy herbivory in this stage. However, some species are excluded, e.g. nectarivorous birds.

Youth phase (up to 4 - 5 years) -- Fynbos is quickly dominated by graminoid herbs and sprouting shrubs (table 6), the herbs reaching maximum biomass of up to 8 000 kg ha^{-1} in the first four to five years. In this period, canopy cover reaches about 80 per cent of pre-burn levels (fig. 1). The remaining sprouting species attain reproductive maturity, while opportunistic shrubs, including succulents, mature and die. Longer lived shrubs begin to emerge from the canopy. The vegetation becomes inflammable at about 4 years, as dead shoots and leaves of hemicryptophytes accumulate and lodge in tufts. Some animal species of the mature community, such as some nectarivores, return to the community.

Transitional phase (up to about 10 years) -- All plant species attain reproductive maturity in this phase. Tall shrubs emerge from the canopy and adopt the ascending branch habit. Remaining nectarivores return.

Mature phase (up to 30 years)-- Tall shrubs attain maximum height and full, rounded form, with maximum flowering activity. Reseeding low shrubs (e.g. Erica spp.) begin to die; litter accumulates and lower herbaceous strata are reduced in importance; no germination occurs.

Senescent phase -- Mortality among seed-regenerating shrubs accelerates, foliage on survivors is reduced to tufts at tips of branches, and crowns become open; with the opening of the canopy, some seed regeneration may occur. Litter and dead shoots continue to accumulate. On special, limited sites that are both fertile and have moist soils, immigration of forest precursors may occur.

Thus, post-fire succession in most fynbos communities is notable for rapid initial recovery due mainly to growth of perennial graminoid herbs (fig. 1, table 6). Although germination after fire may be delayed in some instances, (certain

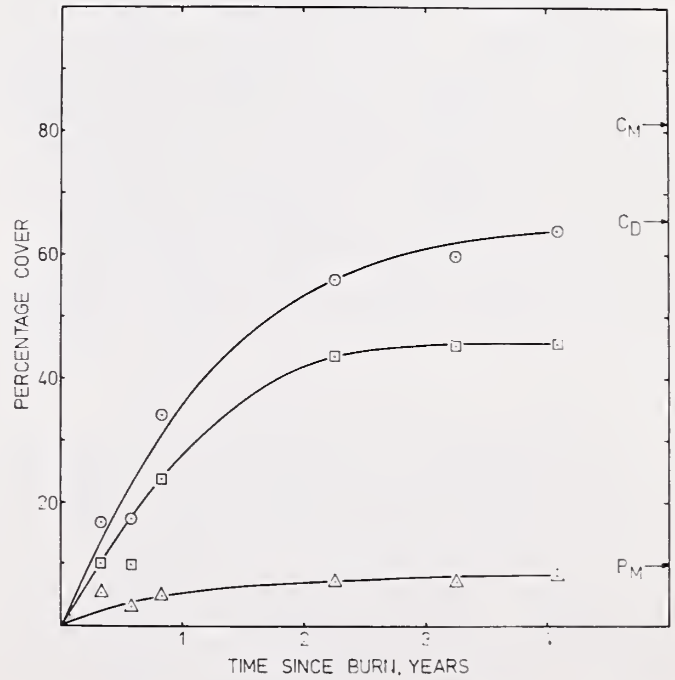

Figure 1 -- Development in plant cover in two communities at Jakkalsrivier, near Grabouw (from Kruger and Haynes, unpublished). Circles represent observations in a mesic community, and squares, those in a dry community. The lower curve represents development in basal cover. C_M and C_D indicate canopy cover in the pre-fire community.

Table 6 -- Changes in canopy cover after fire in a typical fynbos community*

Life-form	Percentage canopy cover at given age (months)											
	7			10			27			39		
	V	G	T	V	G	T	V	G	T	V	G	T
Phanerophyte	2.2	0.4	2.6	3.0	1.4	4.4	4.2	4.8	9.0	5.1	7.1	12.2
Chamaephyte	1.5	0.1	1.6	3.5	0.4	3.9	7.8	4.3	12.1	8.5	4.9	13.4
Hemicryptophyte	8.0	1.1	9.1	18.4	3.1	21.5	31.1	2.6	33.7	31.5	1.8	33.3
Geophyte	3.0	0	3.2	3.7	0	3.7	1.0	0	1.0	0.8	0	0.8
Therophyte	0	0	0	0	0	0	0	0	0	0	0	0
Unclassified	0.8	0.2	1.0	0.2	0	0.2	0.1	0	0.1	0	0	0
Total	15.5	1.8	17.3	28.8	4.9	33.7	44.2	11.7	55.9	45.9	13.8	59.7

*. From F.J. Kruger and R.A. Haynes, unpublished. Data obtained in point-quadrat surveys with only the first strike of a descending needle recorded. Letter codes for columns are 'V' = percentage cover of species with vegetative regeneration, 'G' = percentage cover of species which regenerate from seed, 'T' = total percentage cover for class.

Erica spp. -- Adamson 1935), species richness in the plant community is at a maximum in the immediate post-fire phase and after. Adamson's data suggest some turnover in species in the first few years, but thereafter there is a steady reduction in diversity, as described by Hanes (1971) for chaparral, because there is no germination in most transitional and mature stands (Taylor 1969). Dominance concentration, perhaps initially intermediate falls in the late youth phase when species are roughly equal in height, and then increases to a maximum in the mature phase.

There appears to be considerable migration of animals as different species utilise the changing habitat during the succession. Field observations suggest this, but work of Burger et al. (1977) has shown that the sugarbird (Promerops cafer Linnaeus) requires specific nest-habitats that exist only during the mature phase of the succession.

In contrast succession after fire in fynbos does not include the migration of plant species but represents a process of change reflecting the differentiated life-cycles and growth patterns of constituent plant species. The process contrasts sharply with that in chaparral, for instance: in fynbos there is a much wider range of fire responses, whereas in chaparral the range is restricted to those of the post-fire herb flora and a handful of shrub strategies. In both instances, however, repeated post-fire succession appears to maintain the community.

ECOLOGICAL PRINCIPLES IN PRESCRIBED BURNING : ASSESSMENT

The present policy of prescribed burning in mountain fynbos ecosystems, described by Bands in these proceedings, is based on a series of hypotheses and assumptions, some of which are evident in the account presented by Garnett (1973). The most important of these, ecologically, is that post-fire succession maintains community diversity in the manner outlined above. The required interval between burns is determined by the interval necessary for all plant species to mature and produce sufficient viable seed for reproduction, with the implicit assumption that if the full complement of plant species is retained then the complete natural fauna will survive.

The prescribed season of burn (late summer) has been determined on the assumption that, since most fires in the south-

west occur in that season, the vegetation is best adapted to late summer burns. Since there is evidence of an anticipated interaction between community seasonality and season of the burn, and since there is no evidence as yet of major phenological trends along geographic gradients, this assumption must be revised in the light of major regional differences in fire season.

That prescribed burning is seen as a useful catchment management tool depends in the first instance on the fact that it serves to maintain the natural vegetation as a soil cover and, properly used, is the most economic means of soil conservation. This is supported by the very low sediment yields from both burnt and unburnt upland catchments (Bands, these proceedings), and by the fact that possible undesirable effects on streamflow regime (increased spateflow rates -- Rycroft 1947) are short-lived (Banks 1964). Burning is held also to have a positive influence on water supplies. On the basis of the hypothesis that evapotranspiration from catchments increases with increasing plant biomass, Wicht (1971) postulated that streamflow yields would be influenced by the incidence of fire. This has received some support from a catchment experiment that indicated a 20 mm decline in flow with every year of protection of fynbos against fire (Van der Zel and Kruger 1975). Throughout, it is implicitly assumed that prescribed burning, at favourable seasons, since it simulates a natural process, will not cause irreparable damage to ecosystems, such as a sustained net loss of nutrients.

Accepting that prescribed burning is appropriate and necessary for the conservation of fynbos, one poses the question as to what information is required to ensure that the policy in its variations and refinements is effective in terms of management goals. Present research is directed in the first instance at testing the assumptions and hypotheses outlined above (cf. Van der Zel 1974). Much is highly empirical. One may recognize two classes of information necessary, viz. basic ecological information, and information required for prediction of the effects of different fire regimes in different environments, although the classes overlap. In the first case, there is a need for essential descriptive information on the one hand, to serve as a framework for other ecological data (this includes classification and mapping of vegetation types and related studies), and identification and study of key ecological processes such as the P cycle.

Several key questions relating to the ecological role of fire may be readily identified. The interaction between fire frequency and plant life-cycles is well understood in principle, and the elimination of <u>Protea</u> and other species from short-rotation fire breaks at Jonkershoek serves as one practical example of the effect of a particular frequency. Further information on effects of burning rotation on plant communities will become available from current projects, and relatively simple surveys would indicate minimum fire intervals required for different circumstances. However, the influence of deferred burning on animal habitats, on plant population dynamics and subsequent succession, on fuel accumulation and mineral cycling, is imperfectly understood and requires considerable attention.

The key to understanding the influence of burns in different seasons on subsequent community succession lies largely in an understanding of community phenology, and this almost untouched field is a priority for research. The question is complicated by the interaction between the fire season and intensity of burn. The latter has not been studied at all, although the fact that fynbos fire intensities apparently vary between rather narrow limits suggests that this field of inquiry should not enjoy priority. However, since fire behaviour studies may increase efficiency of prescribed burning operations, their early inception may prove profitable. The reaction of animal communities to different fire regimes is poorly understood, most information being based on observation. This subject requires urgent attention, and should preferably be coupled with the kind of behaviour and habitat studies undertaken by Burger et al (1977), so that change in animal communities may be related to plant succession with reasonable reliability.

Growing demand on the resources of natural fynbos ecosystems will dictate refined management. This refinement will take the form of detailed specification of goals for each management unit, and will demand the means whereby managers

may predict the outcome, ecological and otherwise, of the series of alternate burning regimes and other treatments applicable in a given management unit. This will require thoroughgoing investigation into the ecology of fynbos as a complete field of study, rather than as a study limited to the ecological role of fire as such.

ACKNOWLEDGMENTS

This paper is based partly on the results of the conservation research programme of the South African Department of Forestry and is published with permission of the Secretary for Forestry. I wish to thank the staff of the Jonkershoek Forest Research Station, particularly Ross Haynes, for invaluable assistance. Hugh Taylor contributed through careful criticism of the manuscript.

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PRESCRIBED BURNING IN CAPE FYNBOS CATCHMENTS [1]

D.P. Bands [2]

Abstract: Water supplies from fynbos mountain catchments are of prime importance to the regional economy of the south-western Cape Province of South Africa. Conservation of these mountain ecosystems as water source areas and because of the scientific, aesthetic and economic importance of the natural com= munities, is actively pursued. Prescribed burning is a management tool central to conservation of fynbos. This paper reviews the history of land-use and con= servation practice in these ecosystems, and the evol= ution of present policies. Current practice is brief= ly described and assessed.

Key words: Mediterranean ecosystems, sclerophyll= ous shrublands, conservation, land-use, fire, water resources.

INTRODUCTION

Cape fynbos is essentially a Mediterra= nean-climate vegetation type character= ised by a three-layered structure includ= ing medium to tall sclerophyllous shrubs, low to medium ericoid shrubs and gramin= oid (restioid) plants, and a short graminoid-restioid layer with forbs, adapted to, and apparently requiring periodic fire for the maintenance of its character and diversity (Taylor 1977; Kruger -- these proceedings). Within this broad type there is a wide range of formation classes, including coastal types and a range of mountain formations (Acocks 1975, Taylor 1977). This paper is confined to an account of prescribed burning in Mountain fynbos (Acocks' Veld Types 69 and 70) and the related Mountain Renosterbosveld (Acocks' Veld type 43), as the important catch= ments (or drainage basins) of the region are characterised by these types.

Hall (1976) calculated that fynbos once covered approximately 4.6 million ha, of which roughly three-quarters can be classed as Mountain Fynbos. He es= timated the areas now remaining relatively undisturbed by urban or agricultural de= velopment to be only 1.8 million ha and these are virtually all in the mountains.*

The area of mountainous country that is or was under Mountain Fynbos and that probably will be managed as mountain catchment is approximately 2.7 million ha and approximately 3.5 million ha if related fringing shrubland is included.**

There can be no doubt that the most important role of the Cape folded moun= tains with their cover of fynbos in its various forms is that of water catchment.

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[1] Presented at the Symposium on Environ= mental Consequences of Fire and Fuel Management in Mediterranean Ecosystems, Palo Alto, Calif. Aug. 1 - 5, 1977

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*Estimates determined from Acocks' vegetation map of South Africa and LANDSAT false colour prints.

**Estimates determined by superimposing catchment areas defined in the report of the Interdepartmental committee (Anon. 1961)on Acocks'vegetation map and planimetering.

Table 1 -- Rainfall gradient from Stellenbosch to Dwarsberg, Jonkershoek State Forest

Site	Stel. gaol	Jonkershoek raingauges					
		No.1	No.7	No.2	No.8	No.3	No.17
Distance from Stellenbosch gaol (km)	0.0	7.4	8.7	10.8	12.6	14.9	16.9
Altitude (metres a.s.l.)	107	244	274	293	341	488	1219
Mean annual rainfall	737	1162	1286	1562	1593	2187	3330

Table 2 -- Runoff from mountain catchments in fynbos region

Catchment runoff in mm classes	50	50-100	100-200	200-400	400+
Percentage of total catchment area	22.8	37.3	20.4	9.5	9.9

Soils are normally sands or loamy sands and are highly porous, with a high infiltration capacity. Except in areas with much exposed rock, surface runoff is rare, and erosion rates are low. Mean sediment yield measured in catch= ments receiving about 900 mm of rain= fall per annum were very low, even in those recently burnt, ranging from 0.5 to 10 kg $ha^{-1} yr^{-1}$ (Dept. of Forestry, unpubl.) In areas with rainfall in excess of 1000 mm y^{-1}, stream discharge amounts to 50 per cent and more of the precipitation. Most of the streamflow occurs as winter spates and these flow unused to the sea, but current conser= vation schemes will use this component. Since rainfall and streamflow on the ad= joining lowlands are extremely low (often less than 200 mm rainfall yr^{-1}), the major cities and industries of the Cape Province and a large proportion of its agricultural production depend on the stored winter spate flow from mountain catchment. Goal oriented management to maintain permanent flow of silt-free water from these sources is therefore of prime importance.

The flora of the Cape fynbos and related ecosystems is uniquely rich and has a series of characteristic biogeo= graphic features which warrant its status of one of the six floristic king= doms (Good 1974); it is also by far the smallest. In addition many species are strikingly beautiful. Thus, for scien= tific, aesthetic and economic reasons, conservation of this biome type warrants considerable attention.

The topography and pattern of settlement and development in this region leave the mountains the only relatively extensive tracts of land available and suitable for nature reserves. For= tunately the management requirements of nature conservation and of water con= servation are completely compatible in most cases and on public catchments at least, nature conservation will enjoy equal status with catchment conservation as a management objective.

As mentioned above only an estimated 40 per cent of the former area of moun= tain fynbos remains relatively undisturbed

(Hall 1976). Edwards (1974) estimated that 15 per cent of the area originally mapped as fynbos by Acocks (1953) is conserved. By far the greater propor= tion of the conserved area is Mountain Fynbos and the bulk of this is in State Forests*. Kruger (1977) states that "Coastal and Arid Fynbos are poorly con= served (about 2% of the former in reser= ves), but Mountain Fynbos enjoys good status." In spite of the apparently good conservation status of Mountain Fyn= bos, however, the fact that sections of State Forest may be afforested at some time in the future makes it necessary "to ensure that ecological reserves are proclaimed and managed as such" (Kruger 1977).

Kruger (1977) states further that "the situation with respect to Arid and Coastal Fynbos is extremely critical. Public lands in these types are small or non-existent, and, especially on the coastal lowlands, development has severe= ly reduced the extent of natural communit= ies. Urgent steps will be necessary if representative reserves are to be esta= blished."

Both the scenery and flora of the Cape Mountain Fynbos area have earned enthusiastic praise from many who have had the pleasure of seeing them and, with the proviso that these resources must be conserved, in the true sense of the word, they should be available to the public for their enjoyment, appre= ciation and education, at least on public land. Outdoor recreation is therefore a third invaluable land use of mountain catchments. If unrestrained and uncon= trolled, however, recreational activities can have an undesirable impact on the environment, polluting streams and severly disturbing both flora and fauna. Recreational use can therefore only be permitted under effective control and in forms that are compatible with the prim= ary management objectives of water and nature conservation.

While relatively unproductive in agricultural terms, there are neverthe= less certain uses to which the privately owned mountain lands can be put which are not necessarily incompatible with the goals of water conservation. The extent to which use may be permitted depends upon the economic importance of streamflow from the particular catchment. Most of the uses referred to are of re= latively low profitability and the area concerned would be insignificant in relation to total catchment. Examples are, the cultivation of "bush tea" (Aspalathus linearis L.) or "buchu" (Agathosma betulina (Berg.) Pillans and A. crenulata L. Pillans), on small sandy flats, rarely more than two or three ha in extent, which are characteristically scattered through certain sections of the Cape mountains. These are perennial crops requiring little cultivation or other attention. Access roads frequent= ly cause considerable erosion, as marginal and fluctuating profitability does not permit of great expenditure on road con= struction and drainage. Annually cul= tivated lands are also susceptible to accelerated erosion and are not acceptable in catchments.

Mountain Fynbos is most extensively used for the pasturing of sheep and goats and to a limited extent, cattle. Many farmers maintain that it is uneconomical to make use of mountain veld if they are obliged to abide by the prescriptions, which curtail veld burning and stocking rate. The general opinion that unmodif= ied Mountain Fynbos is unsuitable for pasture is born out by the number of farm= ers who have ignored it in recent years. An estimate based upon enquiry in six catchment areas in the Western Cape in= dicates that only about ten per cent of the fynbos in these areas is currently used for seasonal grazing.

Harvesting of wild flowers and other plant material for both export and the local markets has become extremely pro= fitable over the last decade. The South African Protea Growers and Exporters Association currently represents an in= dustry worth some R3 to R3.5 million yr^{-1}. Flowers and other material have been cut in natural veld for some time with no apparent adverse effect on the ecosystem. The situation must however be carefully watched, and control is necessary. The practice of clearing and cultivating sites in the mountains with the object of sowing or planting more saleable species has led in some cases to serious soil erosion, and access roads, which are no more than rough four-wheel drive vehicle tracks, do untold damage to the sensitive moun= tain environment. Short rotation burning in order to ensure a plentiful supply of certain popular Helichrysum species may

*Any State (public) land reserved for ex= clusive control and management by the Department of Forestry is classed as State Forest.

also have an adverse effect on the ecology and hydrology of the areas where this is practised. Fortunately, as the market becomes more competitive, pro= ducers are finding it more profitable to cultivate the flowering plants intensive= ly on irrigated lands (R.H. Middelmann pers. comm.).

In South Africa it has been general practice to relegate afforestation to sub-marginal agricultural land. For this reason a high proportion of both public and private plantations are es= tablished on relatively steep terrain in mountain foothills of the humid areas (rainfall 800 mm yr^{-1} and more). In many in= stances plantations cover appreciable portions of the catchments of important river systems. Criticism of this situation by agriculturalists and others who fear reduction of streamflow has led to a control system where afforestation requires government authority, which in turn depends on an assessment of the potential impact of afforestation on streamflow in each catchment.

HISTORY OF CATCHMENT CONSERVATION

Early Land Use

There is ample archaeological evidence that aboriginal man made con= scious use of fire in the south-western Cape, at least in his cave dwellings, as long ago as 40 000 years and more (Deacon and Brooker 1976). Whether these very early hunter-gatherers fired the veld regularly and for any special purpose is unknown, but they did utilise plants (Iridaceae) with a pronounced reproduc= tive response to fire (Deacon 1972).

There is some evidence that veld fires may have been an occasional feature of "a more luxuriant vegetation cover than the present Cape macchia" (Hendy 1973, in Klein 1975) in the early Pleisto= cene. Deacon (1972) suggests the possibility that prehistoric inhabitants of the Southern Cape caused a regression in the forest cover by repeated burning. However, it is doubtful whether these hunter-gatherers burnt the veld as re= gularly and extensively as later pastoral immigrants who made their appearance in the fynbos areas some 1700 to 2000 years ago (Schweitzer and Scott 1973, Deacon and Brooker 1976). Mossop (1927) quotes from the diary of Van Meerhoff, who travelled in the Cape about 1660 and reported that his party had to make a considerable detour on their return trip after visiting a Namaqua king, to avoid a fiercely burning veld fire that had been made by the Namaquas in late summer "..for the purpose of pasturing their cattle on the tender grass which appeared after the rains." Mossop also states that Van Riebeek refers to fires made by the Sal= danha Hottentots as they moved with their herds accross the Cape Flats to the Penin= sula. Burrows (1952), writing of a very successful farmer of the early nineteenth century, one Michiel van Breda, mentions that in 1817 he recorded "twenty-seven articles of instruction" to his overseer. Among these was an instruction that "the veld was to be burnt annually to obtain pasturage for the stock".

Early settlers adopted a system of moving their flocks from summer pastures in the mountains to winter in the lower lying Karoo, and of burning the fynbos about a month ahead of returning to the mountain lands. This they learnt from the Khoi-Khoi pastoralists, and the custom has survived to the present day. Signs that this often led to veld degradation and soil erosion can be detected on many mountain slopes in the Western Cape. There is unfortunately a dearth of pu= blished information about early land use practices, and more work is needed in this field to enable an assessment of their effects on the fynbos ecosystem.

In order to supplement their income sheep farmers harvested wild herbs, the most important of which are buchu and bush tea. The buchu market is unstable and has faded considerably in recent years, but bush tea has gained in popularity and is now exported on an appreciable scale. The veld from which these products were harvested was burnt immediately after harvesting in order to stimulate vigorous sprouting of the bushes for the next cut about three years later.

Over the years, with the development of better and more rapid communications, many farmers turned to growing wheat, and established orchards and vineyards. This led to a steady reduction in the utilis= ation of the Mountain Fynbos as the new forms of agriculture were more profitable and it was possible to utilise wheat stubble lands for summer grazing.

Natural fires, that is those caused by lightning or falling rocks are common= place today (see below) and there is no

reason to believe that they were any less common through the ages from pre=historic times.

From the foregoing it is evident that fire and human influence have been a common feature of the fynbos region for a very long time. In fact it may safely be said that modern fynbos has developed with fire as one of the natural factors of the ecosystem.

Natural as it would appear to be in Cape fynbos, fire has been condemned as most undesirable from the earliest days of European settlement in Southern Africa. In the mid-seventeenth century the Dutch East India Company proclaimed severe penalties for veld burning without special authority, and a law passed in 1687 im=posed "severe scourging" for the first offence and "the death penalty by hanging" for the second. This law was re-enacted in 1740 and was still in force when Britain took possession of the Cape in 1806. In 1859 a further Act was passed which laid down a fine not exceeding £100 or imprisonment not exceeding 6 months or combined fine and imprisonment, for the same offence (Botha 1924). These laws were passed not so much to conserve the veld as to prevent destruction of crops, buildings and other property.

In spite of official condemnation of indiscriminate veld burning there have always been those who have either seen no harm in the practice or have in fact even advocated it as being most beneficial in deriving good pasture from "sour"* grassland (Chase 1842, in Thompson 1936). Sparrman (1786 in Wicht and Kruger 1973) suggests that the nomadic Khoi-Khoi pas=toralists understood veld burning better than the settled farmers. They knew the veld well and moved as soon as the grass showed signs of becoming sparse. In contrast, European farmers tended to settle on limited areas and overgrazing followed. Sparrmann commented that the European pasturing customs would adverse=ly affect vegetation, and his opinion was echoed by experts in the subsequent 150 years (Wicht and Kruger 1973).

In 1923 a Drought Investigation Commission expressed the opinion that veld burning was harmful, especially where the water supply of certain areas was adversely influenced. They con=sidered that immediate action should be taken to safeguard certain catchments by forbidding both burning and grazing in these areas.

The Forest Act of 1913 established the intention of the State to maintain streamflow by protecting the vegetation of mountain slopes on Crown (State) land. Considerable areas of mountainous land were entrusted to the Department of Forestry for water conservation and for the protection of natural vegetation. In 1934 the Government was asked to in=vestigate the cause of and take steps to counter the drying up of the country's rivers and to generally conserve the country's water resources. Research into various aspects of veld management for the conservation of water, soil and vegetation was initiated. The Depart=ment of Agriculture commenced a series of grazing trials in grasslands and in 1935 the Department of Forestry esta=blished a research station for forest hydrology at Jonkershoek.

Government reaction to the request for an investigation into the cause of weakening in the flow of many rivers was to appoint an interdepartmental committee for the task. Apart from stimulating research, as mentioned above, the com=mittee's report resulted in new and amended legislation over a period of time, the more important for mountain catchment conservation being the amended Forest Act of 1941, the Soil Conservation Act of 1946, the Natural Resources Develop=ment Act of 1947 and the Water Act of 1947. There have been further more recent revisions and amendments. In terms of the Soil Conservation Act the Minister of Agriculture could appoint Fire Protection Committees. A number were appointed for Cape fynbos areas and it was the duty of these committees to draw up fire protection plans for private=ly owned mountain land, to establish an organisation to implement these plans, i.e. make firebreaks, construct access paths and fight veld fires, and to exer=cise control over intentional veld burning if burning was agreed to be absolutely necessary. The first of these commit=tees was appointed in 1949 and within a few years most fynbos catchments were subject to some form of fire protection. The Department of Forestry provided an exception by approving prescribed burning in the Southern Cape in 1948 as a measure

*In South Africa the term "sour" is applied to grassland which is unpalatable to stock, perennially or seasonally.

for the protection of plantations and indigenous forests (Le Roux 1969).

Foresters and botanists were not unanimous in condemning fire in fynbos, and a prestigious committee, reporting on the preservation of the mountain vegetation of the southern Cape stated in its report that "If pasturage after burning can be prevented ....., this treatment should have a definite place in any plan for preserving the sclero= phyll scrub."(Wicht 1945)

In spite of pressure from many re= sponsible foresters for relaxation of the policy of complete exclusion of fire from mountain catchments, these areas continued to be protected by expensive systems of firebreaks, and all accidental fires were extinguished as swiftly as possible, also at great expense. Pro= posals for prescribed burning were vetoed because managers felt that no firm guide= lines, based upon research findings, as to the correct burning rotations or seasons were available (De Villiers 1963).

For some considerable time then, a policy of excluding fire from land con= trolled by the authorities and limiting burning to the absolute minimum on pri= vate land was in force in Mountain Fynbos ecosystems. This policy dated back to 1876 in the case of the Cedarberg.

It is evident from past reports that conditions of extreme fire hazard are ex= perienced in fynbos areas from time to time. Under such conditions a fire in old veld is uncontrollable and besides burning excessively large areas at one time, can cause considerable damage to property. Examples are the series of fires which broke out in the southern Cape in February 1869 when several lives were lost and many farmers had all crops, stock and buildings completely destroyed (Brown 1875). More recently a fire that swept down from the mountains destroyed 21 houses in a small sea-side holiday village in the Western Cape (newspaper reports, February 1970); Forestry Department records contain many reports of extensive accidental fires that burnt uncontrollably through fynbos which had been successfully protected for up to 40 years. Under severe weather conditions fire in fynbos that has been burnt only six to eight years previously may become uncontrollable, and three to four year old veld can be ignited.

A further undesirable effect of the complete protection of Mountain Fynbos, foreseen as early as the latter half of the nineteenth century (Harrison, in Brown 1875, Phillips 1930, Henkel 1943, Wicht 1945) was the virtual elimination of certain fynbos species (e.g. *Serruria florida* Knight, and *Orothamnus zeyheri* Pappe), which ironically occurred in nature reserves specially proclaimed for these species.

In 1975 Van der Zel and Kruger pu= blished experimental data which supported the hypothesis that evapotranspiration from catchments was positively correlated with biomass and therefore age of the vegetation (Wicht 1971). They found that at the end of a 24 year period of catchment protection the flow of the Langrivier (Jonkershoek) was 26 per cent less than at the beginning, equal to a reduction in annual flow of 500mm rainfall equivalent. Possible detrimental effects of burning, such as increased rates of stormflow (Rycroft 1947) were apparently short-lived (Banks 1964) and erosion rates are low even after fire.

The accumulation of evidence in= dicating that complete fire protection of Mountain Fynbos was not only imprac= ticable, but also undesirable as a con= servation measure, ultimately resulted in the Department of Forestry adopting prescribed burning as a catchment manage= ment and ecosystem conservation tool. The policy calls for prescribed burning with a rotation of about twelve years, and with burning in late summer, although some flexibility in choice of rotation and season is permitted, particularly while large tracts of old veld still exist. Certain types of ecosystems such as relic forests in kloofs, "the true sponges", and the higher peaks, often snow-covered in winter, are not to be burnt, nor are "catchments in the dry areas" (Garnett 1973).

A significant event for catchment conservation, and for conservation of mountain ecosystems, was the promulgation in 1970 of the Mountain Catchment Areas Act, which enables the proclamation of land, whether publicly or privately owned, as Mountain Catchment Area, on the advice of a technical committee. Thereafter prescriptions govern land use and management to ensure more effect= ive control over the country's water catchments.

INCIDENCE AND ROLE OF FIRE

Fynbos, unlike grass-dominated sys= tems, will burn at any season of the year if weather conditions permit. From about the fourth year after burning it will have accumulated sufficient fuel to burn again in humid areas.

Natural fires caused by lightning and rock falls must have occurred at in= tervals of from 6 to 40 years or so, be= cause if they had occurred regularly at more frequent intervals many seed re= generating species would have been eliminated from the system (Kruger in press) and, even after a long period during which every effort has been made to exclude fires, there are few areas of fynbos older than 40 years. As may be expected fuel load increases with age of fynbos and many of the living shrubs are themselves highly inflammable (e.g., Stoebe spp)

Most unscheduled fires occur in summer in the Western Cape winter rain= fall area, and in mid-winter in the Southern Cape constant rainfall zone when warm, desiccating berg winds create con= ditions of extreme fire hazard. The Eastern Cape with its predominantly summer rain experiences most fires in winter although spring is also a time of considerable hazard. Fire seasons are not well defined, however, and no month has been entirely free of fires in any fynbos region over the past ten years. Lightning fires, for example, tend to occur in spring and autumn. (Forest Department, unpublished)

Fire hazard, fuel load and potential fire intensity are positively correlated with post fire age of the veld. Table 5 indicates some intensities that may be expected in fynbos.

Observation of the fynbos ecosystem has indicated that periodic burning is necessary to maintain the complete range of species, of which many utilise only a portion of the post fire development cycle before seeding and dying, to appear again in the same phase of the cycle af= ter the next fire (Kruger, these pro= ceedings). All species observed to date mature and produce sufficient seed to ensure survival within 15 years and most within 10 years (Kruger these proceedings). The faunal elements of the ecosystem have adapted to periodic fires and, as in the case of the flora, many species utilise only certain phases of the post fire development cycle. To conserve the system in all its diversity it therefore appears necessary to burn the veld periodically.

PRESENT MANAGEMENT

There are two categories of catch= ment conservation area under the control of the Department of Forestry namely, public land including State Forests, and declared catchment area on private land. The principal management objective for all catchment areas is maintenance of maximum permanent sustained flow of un= polluted, silt-free water, but subordinate objectives vary depending upon land use priorities. On public land nature con= servation will usually enjoy equal status

Table 3--Incidence and extent of wild fires in the Cedarberg State Forest *

Cause	No. of fires reported					Proportion of total area burnt (per cent)
	Summer	Autumn	Winter	Spring	Total	
Natural origin	14	6	1	10	31	69
Escape from prescribed burn	0	0	1	3	4	10
Negligence	1	6	0	2	9	14
Unknown	2	3	3	1	9	7
Total no. of fires	17	15	5	16	53	
Prop. of total area burnt (per cent)	52	32	0	14		

* From Andrag (1977)

Table 4--Some large fynbos fires (data from Department of Forestry records)

Locality of fire	Area (km^2)	No. of ignit= ion points	Date	Duration (days)	Predom. age of veld (yrs.)
Hottentots-Holland Mtns	112.0	2	Dec. 1942	18	15-20
Hottentots-Holland Mtns	171.3	2	Jan. 1958	16	±16
Du Toits Kloof Mtns*	180.0	5	Feb/March 1971	17	10-20
Krakadouwpoort Cedarberg State Forest*	270.0	±5	Dec. 1972	4	±38
Krakadouw-Groot Koupoort, Cedarberg State Forest	59.5	1	Feb. 1975	5	±40
Kouga Mtns, Baviaanskloof State Forest	187.0	1	May 1975	10	20-35
Sneeuberg, Cedarberg S.F.	135.0	1	Dec. 1975	6	15
Heksberg , Kouebokkeveld Mountains	300.0	1	Feb. 1976	10	30-35
Langeberg Mtns, Garcia S.F. *	26.8	9	March 1977	4	15-25

* lightning fires

Table 5--Estimated fire intensities for a realistic range of fuel loads, under a range of normal fire weather conditions*

	Minimum	Intermediate	Maximum
Available fuel (kg m^{-2})	0.30	0.70	1.00
Rate of spread (m sec^{-1})	0.07	0.28	1.11
Byram index (kW m^{-1})	360	3300	18900

* Fuel estimates based on data in Kruger (1977) and rate of spread based on personal observation.

with water and soil conservation, except for limited areas where timber production from plantations is permitted; and pro= vision for extensive forms of outdoor recreation will be a further objective if compatible with the former. Sub= ordinate objectives for private land are discussed and decided upon with the land owner and the Catchment Advisory Commit= tee.

Nature reserves, set aside to con= serve representative examples of Mountain Fynbos or to preserve rare or endangered species or communities, and Wilderness areas where preservation of wild and un= spoilt natural character is the objective, very often fall wholly or partly within a mountain catchment area. In such cases management emphasis is placed on nature conservation.

Encroachment of alien plant species into fynbos poses severe conservation problems. These weeds, which include _Pinus_, _Hakea_ and _Acacia_ species (Hall and Boucher 1977 list twenty-eight species), spread easily into natural communities, regenerate profusely after fires, and quickly suppress the natural flora. They also aggravate fire hazard problems, and could cause a reduction in streamflow (Kruger 1977a). Control is presently based mainly on manual or

mechanical clearing followed by pre= scribed burns to kill seed and seedlings, and is highly effective. Because of profuse seeding and aggressive coloni= sation strategies, unscheculed fires accelerate the spread of weed species and it is essential to prevent this. The presence of weed species therefore strongly influences veld management techniques, for example fire protection and work scheduling, as no area should be burnt until cleared of mature, standing weeds.

A further point influencing catch= ment prescriptions is that the Forest Act of 1968, as amended, requires pro= perty owners to take precautions against fires escaping from their land. Heavy penalties may be imposed in the event of such an occurrence and the owner from whose land the fire escaped may be fur= ther required to compensate his neigh= bour for damage caused by the fire. As catchment areas usually border upon developed farmlands, town commonage or peri-urban land in various stages of de= velopment, precautions must be taken against prescribed or accidental fires escaping from the catchment and causing damage on adjoining property. Converse= ly, the risk of veld being ignited in those portions of the catchment bordering on more or less intensively settled areas is greater than elsewhere.

Where catchment areas are contiguous with tree plantations, precautions must be taken both against fire damage to the plantations and the spread of pines into the mountain catchment. A peripheral triple firebreak, where each 100 metre strip is burnt in rotation so that no strip is unburnt for longer than 6 to 9 years, is currently the most economical method of satisfying the requirements mentioned above.

As indicated above, the principal management goal is water and soil con= servation but there may be several sub= ordinate objectives, and these may vary from one area of the catchment to another. All management goals must be clearly and unambiguously stated and must be equally clearly prescribed for in a formal management plan.

After each mountain catchment area (which is an administrative area, and may include portions of the catchments, or runoff basins, of more than one river system) has been consolidated by pro= clamation of privately owned mountain land it is planned as a single unit, including both private and public land. The area is first sub-divided according to land use and management objective and is then further subdivided into management units or compartments taking advantage of natural topographical features wherever possible. A prerequisite of a compart= ment boundary is that it should form a practical cut-off line along which fires may safely and easily be set or checked. Where no natural feature such as a ridge or valley is suitably placed it may be necessary to construct a good, well con= toured path to serve as compartment boundary. Unsightly straight line belts are to be avoided. Choice of compart= ment size is influenced by a number of factors; veld management is based upon prescribed burning, and natural fires are thought often to have burnt large areas; an important objective is the creation of a mosaic of different aged veld over the whole catchment to minimize the chances of an uncontrollable runaway fire; and it is necessary to make the most efficient use of labour and other resources. Weather conditions can change dramatically over a twelve hour period in the Cape fynbos region, and it is preferable to be able to complete the burning of a compartment in one day.

Recommendations for management must be based upon thorough knowledge of the catchment. Information about geology and soils, climate and hydrology, fauna and flora, past and present land use, is obtained from map and other published and unpublished records, aerial photo= graphs and field surveys. Note is taken of the conservation status of the catch= ment, soil erosion and presence of weeds or of rare or endangered species or com= munities being of particular importance. Data of value for planning recreational use is collected and sites of special archaeological or historical interest are recorded. Complete descriptive information is recorded for the catchment as a whole and also by compartment.

Those compartments, most commonly private land, to be managed for timber production, pasturing of stock or other compatible goals, are prescribed for individually in accordance with land use and are managed accordingly by the owner. Management of the remaining compartments to conserve the Mountain Fynbos eco= system and water resources will be based upon best current knowledge of the

ecological principles involved. Except where individual species or communities are deliberately favoured, maximum di= versity is the general objective.

Management instructions designed to achieve the specific goals of each compartment and based upon prescribed rotational burning of the veld are drawn up in schedule form. Minimum burning rotation depends mainly upon the juvenile period of the slowest maturing species as determined by the survey; maximum rotation is dictated by acceptable level of fire hazard resulting from fuel build up and must, at this stage, be determined by local experience. A further deter= mining factor is the extent of weed in= festation and the resultant work load imposed by the eradication program. Short rotations (± 6 yrs.) designed to prevent spread of pines into the catch= ment may be prescribed for compartments adjoining plantations even though some fynbos species may be eliminated from these compartments as a result. For the initial burning cycle in the Western and Southern Cape,work schedules and es= timates of labour and other resource requirements will be based upon a 12 yr. average rotation. This will vary from about 8 yrs. in the more humid to about 20 yrs. in the arid areas. A 4 to 5 yr. rotation has been proposed for an area (Suurberg) in the Eastern Cape, but this will almost certainly need to be lengthen= ed if maximum diversity is to be achieved.

While extensive areas of old veld exist in the Western and Southern Cape, burning season is determined by risk in= volved rather than by ideal requirements of the ecosystem. To reduce overall fire hazard old veld is burnt in the early winter or in spring in the Western Cape and in summer in the Southern Cape. Mid-winter burning favours fynbos in the Eastern Cape but farmers in the latter area burn their veld in mid-summer on a 3 to 4 year rotation to eradicate woody species and encourage grass (Trollope 1971).

Summer fires are considered best for fynbos in the Western Cape, as most spe= cies have flowered and produced seed by that time (Kruger 1977), and burning will be scheduled for this season after the first cycle. In order to maintain characteristic diversity, however, burning season should be varied. This is applic= able throughout the range of Mountain Fynbos.

If all fynbos catchment areas are placed on a 12 year average burning cycle the annual prescribed burn program will amount to some 290 000 ha.

Finally provision is made for setting up as comprehensive a monitoring system as management resources will allow, to cover all facets of the ecosystem, includ= ing streamflow, in order to assess the effect of management and provide infor= mation upon which improved prescriptions may be based.

ASSESSMENT AND CONCLUSION

The frequency of large unscheduled fires, and the fact that such fires do not occur where the veld is regularly burnt as under the "patch burn" system observed in the Cedarberg and Olifants= rivier mountains, is a clear indication that prescribed burning greatly reduces fire hazard. In 1970 it was observed how a wild-fire which burnt through 2000 ha of fynbos and destroyed part of a village died out against a 12 month old prescribed burn in the Kogelberg State Forest; and in 1975 an unscheduled fire which burnt through a 3 year fire break was arrested both by a recent pre= scribed burn and by patch burnt private land. Only counterfiring was effective elsewhere.

Evidence of the effectiveness of prescribed burning as a conservation tool may be found in the dramatic response of Orothamnus zeyherii Pappe to this treat= ment in the Kogelberg State Forest, where the population was boosted from a known 6 individuals on only a single site in February 1968, to over 1900 on 10 sites in 1975. Some of the populations had apparently become extinct before the burns (Boucher and McCann 1975). Several other rare and attractive fynbos plants have been successfully rehabilitated by this means. The same measure of success cannot be claimed in the case of the Clanwilliam cedar (Widdringtonia cedar= bergensis Marsh), however, and an effec= tive means of ensuring the perpetuation of this species is proving ellusive.

Many birds and animals move out of old veld as their food plants are sup= pressed and free movement becomes diffi= cult. Species such as Francolin (Franco= linus spp) Grey Rhebuck (Pelea capreolus) and others respond positively to post-fire growth in fynbos.

Fire, correctly used, is effective in eradicating alien plants; and those who enjoy their recreation in the Moun= tain Fynbos environment will agree that although unsightly immediately after burning, the vegetation soon recovers and is most attractive as it develops through its seral stages.

Weight of evidence, therefore, is of success of prescribed burning as a measure for achieving the major manage= ment goals in Mountain Fynbos, but it is also evident that our knowledge of this ecosystem and its requirements for effec= tive conservation is far from complete. The Mountain Fynbos ecosystem is an in= tricate complex and it is unlikely that any rigid or simple approach will ensure maintenance of its characteristic diver= sity. Management must be as flexible as practical considerations will permit.

ACKNOWLEDGMENTS

This paper is based on the South African Department of Forestry's con= servation research and planning program, and is published with permission of the Secretary for Forestry.

The invaluable assistance of Mr. F.J. Kruger, who criticised this paper is gratefully acknowledged.

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THE CALIFORNIA MEDITERRANEAN ECOSYSTEM AND ITS MANAGEMENT[1]

John W. Menke and Ricardo Villaseñor[2]

Abstract: The climate, vegetation, soil and wildlife of the Californian Mediterranean ecosystem are described in context with fire as a natural component of the system and fire as a management tool. Past and present management practices, policies and problems are discussed briefly.

Key words: Chaparral, Mediterranean ecosystem management, fire effects, fuel management, brushland management

ECOSYSTEM DESCRIPTION

Outstanding Climatic Features

Climatic boundaries must be defined to characterize the Mediterranean regions of California. Any such boundaries are of course subject to a certain degree of variance and subjectivity of the mapper. Comparing worldwide climatic zone characteristic of "Mediterranean" vegetation, a close association can be recognized. Aschmann (1973) notes three climatic parameters as determinate of Mediterranean regions, total annual precipitation, seasonal precipitation pattern, and mean minimum temperature of the coldest month or percentage of hours in the year with temperatures below freezing. An additional climatic feature which is important in the fire ecology of this region is the common occurrence in the fall of foehn winds.

Characteristic of all Mediterranean regions is a seasonal precipitation pattern of a wet season in which the great majority of rainfall occurs followed by a dry season. Aschmann (1973) determined a lower boundary of 65% of total annual precipitation during the wet season in Mediterranean regions around the world. In California as much as 80-90% of the year's precipitation may occur in the months November through April. Cooper (1922) cites a lower boundary of 20% total annual rainfall during the summer months in the California broad-sclerophyll vegetational regions. Cooper's emphasis was on the regions where the broad-sclerophyll vegetation dominated. The correspondence of these vegetational regions to that of the 20% summer rain boundaries is quite remarkable.

Total annual precipitation in Mediterranean regions as determined by Bailey (1958) using the definition of moisture effectiveness as the ratio of total precipitation divided by temperature, corrected by seasonality of precipitation, is in the range of 11 to 35 inches per year. Cooper (1922) cites a range of 10-30 inches in his California study.

Temperature regimes characteristically show short maximum-minimum seasonal ranges in the Mediterranean regions. In California these relatively narrow seasonal temperature ranges are due to the stabilizing marine influences. Mild winters are also a characteristic of Mediterranean regions. A good index of the severity of winters is the proportion of time that temperatures are below 0°C. Bailey (1966) set a limit of 3% of the total hours per year in which temperatures are below freezing in Mediterranean regions. The Koppen (Köppen and Geiger 1936) climatic classification has a cold boundary of -3°C at 6% of the total hours per year. Ackerman (1941) using the Loppen classification in North America established a cold boundary of 0°C at 4% of the total hours in tye year. Using

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Bailey's formula for determining the percentage of hours in a year below 0°C from the annual range of mean monthly temperatures for selected sites in California and comparing to a mean minimum temperature of 32°F in January, which corresponds to Cooper's value, the two criteria agree very nicely.

Summarizing briefly, the Mediterranean climatic region in California may be characterized by 1) a concentration of total annual precipitation (80-90%) in the months November through April; 2) a total annual precipitation range of 10-30 inches; 3) a mean minimum temperature in January (coldest month) of 32°F.

An additional climatic variable of California's Mediterranean regions which is important to fire ecology is the occurrence of foehn winds. Foehn winds are a special type of local wind associated with mountain systems. In southern California these winds are termed Santa Anas or Santanas and in northern California they are called Northers or Mono winds. These winds require a strong, usually stagnate high-pressure air mass in the Great Basin area east of the Sierra Nevada Mountains with a corresponding low pressure center on the opposite side of the ranges, creating a strong pressure gradient across the mountain barrier. The air flow comes from aloft in the high pressure area due to the blockage of surface air flow by the mountains. This air is warm and dry and flows down the leeward side of mountains towards the coast. Speed, duration and altitude of these winds are all determined by the magnitude of the pressure gradient. Wind speeds of 40 to 60 miles per hour, lasting for 3 or more days are common. These conditions of stagnate highs to the east with lows to the west are common during the fall and late summer months. The combination of warm, dry strong winds following the drought season produce pronounced fire weather conditions. Oftentimes when a fire does occur during these conditions it rages uncontrollably in California's wildlands.

Vegetation

General Description

The vegetation of the Mediterranean region of California may generally be described as a woody vegetation complex composed of evergreen forest, scrub, drought deciduous scrubs, woodland savannas and a unique type, chaparral, recognized as the characteristic vegetation type of Mediterranean regions around the world (Mooney, Dunn, Schropshire and Song 1972; Specht 1969a & b; Naveh 1967). The classification of the vegetation within this region has received a variety of treatments over time and it may be helpful to quickly summarize three of these classification efforts to gain an understanding of how the vegetation within this region has been analyzed.

Cooper (1922), in his description of the broad-sclerophyll vegetation of California, used the term formation as the fundamental unit of vegetation. Each formation was based on the relatively ecological homogeneity dominants (ecological character), the common dominance by one or more species in each subdivision or association (floristics), the exhibition of a constant successional role (development) for each given climatic region. Each association within a formation may deviate from any or all of the criteria of the formation to a minor degree but not sufficiently to cause it to stand out as a distinct entity. There are two Californian formations recognized by Cooper in which the broad-sclerophylls are dominant -- the Broad-Sclerophyll Forest Formation and the Chaparral Formation.

Cooper's Broad-Sclerophyll Forest Formation has a range from southern Oregon southward through the coast mountains and Sierra Nevada foothills into Lower California. It occurs in discontinuous patches within its range alternating with chaparral and overlapping with the ranges of Sequoia and Pseudotsuga associations of the conifer formation. This formation is thus found on the mesic boundary of the Mediterranean vegetation type and is more important in the north, especially in the Coast Range. Southward the Chaparral Formation becomes more predominant. Within the Broad-Sclerophyll Forest Formation, Cooper identified a number of associations and noted that wherever the broad-sclerophyll communities adjoin the conifer forest they pass into the forest as layer societies. There is a close habitat relation between the broad-sclerophyll forest and the chaparral, in that in the main they overspread the same range, and differ in many areas in slope exposure only.

The Chaparral Formation is made up of two associations, the Climax Chaparral and Conifer Forest Chaparral Associations. The Climax Chaparral Association is the dominant community over the whole of the Southern Coast Range and the mountains of southern California. Only the highest summits dominated by conifers and the more mesic north slopes with the broad-sclerophyll forest are expected. The Climax Chaparral Association disappears as a dominant community at the north end of the Sacramento Valley. This association is of great importance in the Southern Sierra Nevada Mountains with its continuity broken as you move northward. Cooper notes that the climax chaparral

is by far the most widely extended and diversified of the broad-sclerophyll communities. *Adenostoma fasciculatum* makes up a striking and characteristic consociation which has been referred to as "hard chaparral".

The Conifer Forest Chaparral Association occurs in the mid-altitudes of the Sierra Nevada Mountains with colonies throughout the higher mountains of northern California, north Coast Ranges and the mountains of southern California. There is extensive overlap with the range of the Climax Chaparral Association. Cooper feels this association is for the most part a successional community maintained on pine forest areas by repeated disturbances like fire. The dominant shrub species are often found as understory species in the transitional zone with *Pinus ponderosa* forest.

Jepson (1925) classified California's vegetation according to Merriams (1898) "life zones" based upon climatic factors. Within each life zone, Jepson listed index species. The Mediterranean ecosystem would fit into the Upper Sonoran Zone and the Transition Zone. The Upper Sonoran Zone is made up of two subareas, the Lower Foothill belt and the Chaparrel Belt. The Lower Foothill Belt is a grassland formation with scattered growth of *Quercus douglasii* and *Q. engelmannii*. Cooper felt this formation was a successional stage to chaparral and therefore did not recognize it as a separate formation.

The Chaparral Belt is above the Lower Foothill Belt and corresponds to Cooper's Climax Chaparral Association. It has an average altitude range of 1000 to 4000 feet. This sub-life zone is always a mixed formation with characteristic species being *Ceanothus cuneatus*, *divaricatus* and *serediatus*, *Arctostaphylos glauca*, *glandulosa*, *viscida* and *canescens* and *Cercocarpus betuloides*. Chamisal Chaparral is a pure formation of *Adenostoma fasciculatum*.

The Transition Life-Zone is very similar to Cooper's Conifer Forest Chaparral Association. The Arid Transition (subarea in Transition Zone) of the Sierra Nevada Mountain and Coast Ranges is on the mesic border of the Mediterranean ecosystem with index species of *Pinus ponderosa* and *Quercus Kelloggii*. Jepson makes the important point that boundaries of the zones and therefore the plant species associated with them are irregular and determined by exposure, insolation, steepness of slope, local temperature conditions, physiological islands and fire.

Munz and Keck (1959) use floristics as the basis for their plant community classification. The Mediterranean vegetation includes the Coastal Sage Scrub, Closed-Cone Pine Forest, Yellow Pine Forest, Mixed Evergreen Forest, Northern and Southern Oak Woodland, Foothill Woodland, Chaparral and Valley Grassland plant communities. Each plant community has its indicator species. Cooper's Climax Chaparral Association can be equated with Jepson's Chaparral Belt and Munz and Keck's Coastal Sage Scrub and Chaparral communities. The Broad-Sclerophyll Forest Formation is equated to Munz and Keck's Oak Woodlands, Foothill Woodland and Mixed Evergreen Forest. Cooper's Conifer Forest Chaparral Association may be most closely related to Munz and Keck's Closed-Cone Pine Forest and Yellow Pine Forest and Jepson's Transition Zone.

The distribution of the broad-sclerophyll vegetation in California can generally be defined as extending from the coast to the middle altitudes of the Sierra Nevada and Coast Ranges, not including parts of the San Joaquin and Sacramento Valleys. The northern boundary may be at the foothills of the Trinity and Cascade Mountain Ranges surrounding the Sacramento Valley and extending south to the Mexican border near the coast. It may be thought of as a belt of vegetation bordered at its mesic edge and with the coniferous forest type and at its xeric edge by the deserts to the east. Dominance decreases north and east and as altitude increases (Cooper 1922).

The Chaparral vegetation type has been recognized as the characteristic vegetation type of Mediterranean regions around the world, thus it will be emphasized from this point on. In California, chaparral has a general distribution as described above and covering about 8.5% of the total area of the state. Further north in the Coast Ranges and Sierra Nevada Mountains, chaparral is more and more restricted to south-facing exposures with other exposures being occupied by taller broad-sclerophyll forests. Chaparral reaches its fullest development in southern California from 1000 to 5000 feet and in the northern portions of its range it extends from 500 to 3000 feet. To the south hard chaparral or chamisel chaparral is bordered on the coast with soft chaparral or coastal sage scrub, this association declines in importance as you move north.

The general physiognomy of chaparral is brush vegetation, closely branched, 2-10 feet tall, one-layered and very dense. The phenology of chaparral plants, characterized by a number of investigators (Hellmers and Ashby 1958; Miller 1947; Sampson 1944; Mooney and Dunn 1970), shows the growing season is closely related to soil moisture. Maximum air temperature is not a critical factor in determining the onset of active growth in chaparral scrubs,

but growth seldom occurs with a maximum temperature below 23°C. Minimum temperatures exert a controlling influence on the inception of growth. Temperatures must rise above freezing before active growth may begin. Cessation of growth is produced by environmental factors which produce higher evaporation rates (Miller 1947). There is little or no growth in summer when temperatures are high and relative humidity is low. With its leaves designed to minimize evaporation and transpiration from the leaf surface, and a deep root system utilizing all available ground water, these plants retain their leaves through the drought season. This allows the plants to be opportunistic when rains do occur since energy to produce new leaves is not wasted and can be effectively used for plant growth and development.

Growth begins in early winter but reaches a maximum in late winter and early spring. Flowering begins during the maximum growth period and is completed in June just before the soil moisture drops below the wilting point. Extremes in temperature and the precipitation pattern appear to be the important climatic factors determining the distribution of the chaparral vegetation (Sampson 1944). In addition to these climatic factors, disturbances, exposure, and steepness of slope all contribute to the local environmental conditions giving rise to the vegetation community. Local conditions of soil and slope may greatly modify regional climate effects.

Hanes (1971) maintains that slope aspect is the most important selective factor in the chaparral environment. It strongly influences which species make up the local chaparral community and the changes and rates of succession in the community following fire or other disturbances. Miller (1947) was able to measure and quantify the differences in evaporation rates, air temperature, soil temperatures and soil moisture throughout the year for north versus south slopes in a chaparral community in southern California. Slope exposure showed a close correlation with vegetational differences and local environmental conditions. South slopes with hard chaparral above 2000 to 5,500 feet showed a greater evaporation rate and ranges in air and soil temperatures. North slopes with chaparral from the foothills to 4000 feet give way to broad-sclerophyll woodland. Higher evaporation rates were significantly affected by the angle of the slope, the steeper the angle on south facing slopes the greater was the evaporation rates. Vogl and Schorr (1972) believe that vegetation competition between chamise and manzanitas is affected by the amount of ash on a site after fire as determined by the angle of the slope.

Since chaparral grows on land with a variety of slope exposures and steepnesses, these factors cannot be ignored in a local area, much less in a regional perspective. These relationships produce a great variety of chaparral associations and boundary interactions which result in a diverse vegetation type with a patchy distribution.

Fire Adaptations

Fire is an important component of the chaparral ecosystem. There are a number of factors which make this vegetation a "fire-type" and one of the most fire susceptible in the world.

The growth structure and habit of the vegetation contribute to the flammable nature of the chaparral. There are 4 basic descriptors of fuels which have been applied to the chaparral vegetation (Countryman and Philpot 1970):

1) Surface-to-volume ratio: The greater this ratio the faster the fuels will be heated to ignition thereby increasing the rate of spread.

2) Fuel bed porosity: The amount of air space in the fuel bed realtive to the amount of fuel. As the porosity increases to an optimum the burning rate increases.

3) Ratio of dead to live material: The moisture content of fuels in all seasons is lower when the ratio of dead to live materials is higher. Fuels available to fire increase with lower fuel moisture contents.

4) Fuel loading: The greater the fuel loading the greater the "thermal pulse" or energy output observed from a fixed point.

In each case chaparral has a growth habit which increases each factor through time. Small leaves and twigs increase the surface-to-volume-ratio; a "laddering" of dead material throughout the canopy increases the fuel bed porosity and fuel loading.

A very important characteristic of this vegetation which makes it a "fire-type" is that it retains a significant amount of dead material in its canopy. Studies on chamise (Adenostoma fasciculatum) (Countryman and Philpot 1970; Dell and Philpot 1965) have exemplified how this brush produces a fuel bed for rapid burning. In dead fuels, moisture content is directly related to weather conditions. During the drought season when temperatures are high and relative humidity low, these fuels are prime targets for fire. Add to this the desiccating effects of fohen winds and it leads to comments like "If we deliber-

ately set out to construct an artificial fuel bed for rapid burning it is unlikely we could do much better than chamise does naturally." (Countryman and Philpot 1970).

A physiological factor which contributes to the flammability of chaparral is the presence of highly flammable, volatile terpenes in the leaves which also produces the aromatic character of the vegetation.

The vegetation has responded to recurrent fire by employing several strategies to insure continuance of the species. Three such strategies are 1) sprouting, 2) serotinous cones in pine species, 3) seeds requiring heat for germination.

1) Sprouting: About half of the species of the California chaparral are rootcrown sprouters. These species can usually withstand repeated burning without dying or loss of vitality. This vegetational response is independent of the rainy season; the new shoots apparently draw on water reserves of the root system. Usually sprouting begins from a week to ten days after the fire and is followed by a very rapid growth rate. This reproductive response obviously gives the plant a decided advantage over nonsprouting species.

2) Serotinous cones: Some of the _Pinus_ species which occur in transitional zones have developed cones which require intense heat to induce opening. These species occur on the mesic border areas of the Meditarranean region in woodland savannas and closed-cone pine forests. Three species occur in California: _Pinus attenuata_ (knob cone), _Pinus muricata_ (Bishop) and _Pinus radiata_ (Monterey). These pine species have developed this unique method of seeding in response to the common occurrence of fire. Seed bed conditions are improved after fire and the threat of fire to the vulnerable saplings is reduced as a result of reduced fuel loading.

3) Heat dependent seeds: Nonsprouting brush species as well as some sprouting brush species and herbacious species have tough, thick seed coats that act as effective insulators and prevent the embryos from germinating. The seed coats are impermeable to moisture until temperatures reached in fires crack the seed coat allowing the seed to imbibe moisture and begin the process of germination. Seeds of this type may be stored in the soil for many years awaiting fire. Many seeds of herbaceous species which germinate during that first year following a fire have been stored in the soil since the last fire (Sweeney 1956). The temperatures and duration of heating required for germination vary among species. (Stone and Juhren 1951; Went, Juhren and Juhren 1952; Stone and Juhren 1953)

Succession

Following fire, chaparral has a remarkable recovery potential. In the California Mediterranean region there are a variety of climax plant communities due to the variety in topography and climatic ranges. In one area a community may be considered climax and in another a successional stage. Cooper maintained that the Broad-Sclerophyll Forest Formation is a potential climax in southern California, climax on north facing slopes in central California and less dominant in northern California where it becomes a successional stage to the conifer community. Chaparral is now generally recognized as a climax vegetation type which requires fire to insure its existence. On many sites is is probably the only vegetation which can maintain itself. The center of its distribution is considered to be in southern California on steep slopes and shallow soils. Its occurrence on gentler slopes with deeper soils next to grasslands has raised the question of its claim as climax vegetation or as a successional stage. Conversion to grasslands has been successful in northern California where the chaparral climax quality may be relegated to more selected sites than in southern California. The general successional pattern in chaparral may be summarized as follows:

1) First 1 to 3 years the ground is covered by annual and biennial herbaceous species, brush seedlings, and sprouts. Species diversity is greatest at this time and decreases as succession continues. The area is dominated by annual low growing herbaceous plants.

2) Second stage is marked by the absence of the herbaceous species for 5-10 years and the dominance of the brush, both permanent and intermediate successional species.

3) At 15 to 30 years the intermediate shrub species, such as Ceanothus, begin to die further reducing species diversity and the longer lived sprouting species, like chamise and manzanita, increase their dominance. This is also the stage when dead material in the canopy increases thereby increasing the probability of fire.

4) Beyond 35 or 40 years of age the vitality and productivity of the stand decreases as the stand enters decadence. More and more dead material accumulates and in more cases burns before it gets much beyond this stage (Hanes 1971; Sampson 1944; Vogl and Schorr

1972; Horton and Kraebel 1955; Cooper 1922; weeney 1956). There is variation in successional rate and species depending on site exposure (north versus south slope), site quality (shallow versus deep soils), geographic location (northern California versus southern California) and season of burn. The temporary cover for the first few years tends to be dominated by annual grasses in northern California. There is more herbaceous cover at higher successional in northern California than in southern California (Horton and Kraebel 1955). Vogl and Schorr (1972) noted a faster successional cycle in the higher elevations but the stages were similar.

In summary, the general successional pattern in chaparral vegetation after fire follows a progression from a diverse multi-species herbaceous and shrub community towards a dense, structurally uniform, low diversity stand of brush species. In some areas further succession beyond the brush stage may proceed to oak-woodland. Due to the sprouting habits and seeding ability of the chaparral species, it succeeds itself rather than proceeding to another vegetation type. Since fire is required to ensure chaparral vitality, suppression efforts have succeeded not only in allowing dead materials to reach a critical fire level, but have threatened the survival of this fire adapted vegetation type (Dodge 1972).

Soils

General Description

The soil-types within the Mediterranean region in California vary a great deal from very shallow rocky, coarse textured soils on steep, south facing slopes to the deeper more clay containing soils on the gentler slopes and flat land. This range of soil types can occur within very short distances of each other, from the top of a ridge to the valley bottom.

Physical Properties--Chaparral is tolerant of widely different soil conditions and is found on a large number of soil series (Weir and Storie 1936). Soil development is dependent upon the topography, geology and climate prevailing in a particular area. On steep slopes (50 percent or greater) the soils are characteristically shallow, coarse textured, with a weak, angular, blocky structure. The soil surface is usually rocky with more than 10 percent of the surface covered with rocks larger than 3 inches in diameter. Bulk densities vary from 1.04 grams/cubic centimeter at the surface to 1.79 grams/cubic centimeter in the underlying subsoil (Holzhey 1968).

On gentler slopes and flat areas the soils tend to be deeper, containing larger amounts of clay, sometimes exceeding 20 percent. The percentage of rock and stones in these soils is less than on the steeper slopes. The higher percentage of clay tends to produce a strong blocky to subangular blocky structure (DeBano 1973).

Soil depth is of slight hydrologic importance, since the parent material differs little from the soil in its hydrologic properties (Krammes 1968). Steep slope areas are generally characterized with high erosion rates and rapid runoff during intense storms. Rainfall intensities are rarely so high that water runs off the surface. At the San Dimas Experimental Forest in southern California only about 2.5 percent of the precipitation fell at a rate higher than the infiltration rate of the soil in 24 years (Rice 1973). About 25 percent of the yield downstream is in the form of streamflow, the remaining 75 percent moves from the watershed as groundwater (Hill and Rice 1963).

The erosion processes in steep chaparral watersheds (slopes over 50 percent) are quite different than the erosion processes of flat lands. Except for a few years immediately after a fire, bare soil is a rarity. It is only during this time that raindrop impact is an important erosion mechanism. Sheet erosion is of minor importance due to the concentration of overland flow into rills and gullies. The most significant source of erosional energy is gravitational erosion. Dry gravel (Anderson, Colman and Sinke 1959) is a major eroding agent in chaparral areas occurring on slopes steeper than 60 percent. A second gravitational mechanism of erosion important to chaparral areas is landslides. Most landslides are the product of storms of such size that they occur on the average only once in every 8 to 10 years (Rice 1973).

Fire has some definite effects on the physical properties of chaparral soils. The physical structure is changed in the upper soil layers as the organic matter is destroyed. The aggregating properties of organic matter is lost and some of the large pores, which improve movement and aeration, are lost.

Changes in the soil wettability directly effects the erosion processes (DeBano, Osborn and Krammes 1967). Hydrophobic layers occur parallel to the soil surface at varying depths and thicknesses as determined by fire temperatures, soil physical properties, soil water

content and vegetation factors. The hydrophobic substances originate in the decomposing plant litter. When fire occurs these substances are vaporized and distilled to lower soil levels and condense on soil particles in response to the larger temperature gradients. Coarse-textured soils are coated more completely than the finer textured soils due to the lower surface to volume ratio (DeBano, Mann and Hamilton 1970). Wet soils tend to have the hydrophobic substances concentrated in a thin layer near the soil surface.

The water repellent layer has in effect reduced the hydrologically active mantle from several feet in thickness to only a few inches or less. Even small storms exceed the capacity of this thin layer to transmit and store water and saturation occurs more often than on unburned areas. Changes in overland flow from 1 percent in unburned watersheds to averages of 10-15 percent on burned watersheds have been observed (Rice 1973).

Soil temperatures are normally affected by soil depth, site exposure and vegetation cover. Miller (1947) found higher soil temperatures on south slopes than those on north slopes. The range of soil temperatures was considerably reduced for deeper soils. Although only about 8 percent of the energy released by burning fuel is absorbed and transmitted downward in the soil, temperature increases can be significant, especially at the surface. With increasing depth these temperature effects are reduced along a steep gradient.

Erosion is increased after fire has removed the vegetation. The magnitude of this increase is dependent on the storm sizes, amount of vegetation removed, degree of water repellent layer development and amount of time required to re-vegetate an area. The destruction of organic matter and therefore the soil structure decreases the infiltration rate. This coupled with the removal of plant cover and the creation of water repellent layers increase surface runoff and erosion.

Chemical Properties--It is generally recognized that a majority of chamise brushland soils are low in fertility. The Mayman soil series, which probably forms a larger area than any other chamise brushland soil in California, is the least productive except for serpentine soils which may also support chamise. Productivity may range from very poor to a high enough quality that the areas have been cleared of brush cover for agricultural use (Biswell et al. 1952). The soil pH is generally neutral at the surface to slightly acid at 2 feet below the surface. Usually less plant nutrients are present in chaparral soils than in those soils used in agriculture.

Nitrogen is most frequently the limiting nutrient (Hellmers, Bonner and Kelleher 1955). The species growing on a soil may greatly effect its fertility. Certain brush species have been shown to increase soil nitrogen levels by fixing atmospheric nitrogen. Up to 50 pounds of nitrogen per acre per year has been added by scrub oak (Quercus dumosa) and wavey leaf ceansothos (Ceanothus crassifolius), whereas chamise (Adenostoma fasciculatum) depleted nitrogen at about the same rate (Zinke 1967). One of the characteristic features of chaparral vegetation which has a significant effect on the fertility of the soils is its retention of dead material in its canopy thereby tying up nutrients in the standing dead biomass.

The role of fire in affecting chemical changes in the soil is not fully understood. The most obvious change is the destruction of plant litter and organic matter at the soil surface. The amount of total organic matter destroyed depends on the temperature and intensity of the fire. Studies have shown a decrease in soil organic matter within the first couple of centimeters between 40 and 50 percent (Christensen 1973; Ahlgren and Ahlgren 1960). Fire releases plant nutrients in readily available forms. Before fire, these nutrients are contained in living and dead plant tissues and are unavailable for plant growth. DeBano and Conrad (in press) measured the nutrient content of the standing plant, litter and soil before and after fire. Reviewing some of the important nutrients, phosphorus, potassium, magnesium and nitrogen, they found in each case an immediate increase in soil nutrient concentration. Nearly all of the phosphorus contained in the plant material was returend to the soil in the ash. The potassium content increased on the surface with ash deposition. There was some loss associated with volatilizatior when temperatures reached greater than 550°C. Magnesium concentrations were about equal to the potassium concentrations in the litter and plant material prior to the fire. After the fire 76 percent of this amount was deposited as ash.

Nitrogen changes in response to fire has received a great deal of attention (Christensen 1973; Christensen and Muller 1975; Sampson 1944; DeBano and Conrad [in press]; Dunn, DeBano and Eberlain [in press]). DeBano and Conrad (in press) found a significant loss of total nitrogen after fire due to volatilization. This loss was a function of the intensity and duration of the fire. Volatile losses of 20-40 percent have

been noted (Christensen 1973; DeBano and Conrad [in press]). Although the total nitrogen content on the site is reduced with burning, the amount of available nitrogen is increased. The ash is low in nitrate levels but high in ammonium levels; this increases the pH of the soil, favoring microbial activity. Studies have recently indicated that nitrogen levels, both total and available, are greatly affected by the soil moisture content at the time of the burning (DeBano and Conrad, Dunn, DeBano and Eberlein [in press]).

Nutrient losses in debris and runoff have long term impacts on chaparral soils. As mentioned above, fire does increase runoff and on the average nearly 70 percent of the long term sedimentation from a watershed occurs in the first year after a fire. Under most circumstances more than half of the sediment load originates from deposits accumulated in the stream channels since the last major flood (Rice 1972). However, this increased runoff and debris loss has been shown to account for less than 6 percent of the total nutrient loss from the upper 2 cm. of the soil and litter layers.

There has been little work done on the decomposition rates of biomass in or on the surface of chaparral soils. Kittredge (1955) quantified these rates under different stands of brush. Generally, due to the warm, dry climate and the high lignin content of the plant tissue, these rates are relatively slow.

Biological properties--There is almost total absence of published information on soil animal communities in California. Using data from Mediterranean regions around the world and comparing them to some preliminary studies done in California, DiCastri (1973) provides information as to the structure of the soil-animal communities. Particular attention is directed at physiognomy, stratification, density, aggregation, affinity, species diversity and phenology. These community properties are largely determined by the humus which in Mediterranean ecosystems tend to be poor and very specialized. Of course there is a feedback mechanism at work here since the humus characteristics depend ultimately on the activities of the soil organisms.

Information on microbial activity is also largely unknown except for introduced exotic legumes used in range forage improvement programs. Little is known about the relationships between the external environment and the soil microclimate. The precise effects of plant cover, litter type, and soil and been largely ignored. These points made by Schaefer (1973) point out areas of needed research to make the present picture of microbial activity clearer in Mediterranean ecosystem. The seasonal variation in microbial activity has been characterized by two growth flushes, one at the onset of the drying phase or drought season and the other when soil moisture is replenished in the fall. The first is due to thermal activation and the second, the removal of drought as a limiting factor.

Direct effects of fire on the microbial community may be as dramatic as the chemical changes (Dunn, DeBano and Eberlein [in press] The degree of soil sterilization appears related to fire intensity and duration and soil moisture content. Heterotrophic bacteria are better able to survive soil heating than heterotrophic fungi. Reinvasion of heterotrophs soon after the fire are aided by the higher pH conditions produced by the fire, the increased soil temperature with increased solar radiation and moist conditions with the first rains. A second way fire can affect microorganisms is by the altering of organic matter by making it more easily mineralized. These available organic nitrogen compounds probably stimulate heterotrophic growth.

Nitrification following fire may play an important role in the nutrition of the various plant species reinvading an area. Nitrification is generally considered to be carried out by Nitrosomonas and Nitrobacter bacteria (Focht and Verstraete [in press], Rice and Pancholy 1972). Both seem to be sensitive to disturbance and recover slowly (Walker 1975). Nitrosomonas group bacteria utilize ammonia nitrogen as an energy source and produce nitrite nitrogen which is in turn used by the Nitrobacter group bacteria as an energy source to produce nitrate nitrogen. A mixture of ammonia nitrogen, produced by the fire, and nitrate nitrogen is assumed to be the nutritional preferences of chaparral species (Dunn, DeBano and Eberlein [in press[). Since these two groups of nitrogen fixing bacteria require some time for reinoculation after fire, it is believed the immediate nitrification is carried out by other heterotrophic microbes directly from protein nitrogen sources.

Wildlife

Studies on the response of wildfire to fire in the chaparral have provided little evidence of direct mortality due to the fire, but have shown population changes in response to habitat change (Cook 1959; Lawrence 1966; Biswell et al. 1952; Taber and Dasman 1958). Most vertebrates are able to avoid the fire by evacuation or burrowing in the ground. Birds

may lose eggs and young in the nest; amphibians, reptiles and small mammals may be trapped and killed in the litter. Those that live in burrows can retreat below the surface where the soil provides adequate insulation from the heat. A depth of 4 to 6 inches is normally deep enough to escape the heat. A more critical factor in burrow survival than temperature is probably vapor pressure. Vertebrate temperature regulation is frequently accomplished by the evaporation of moisture from the surface of the lung, dissipating heat. This evaporation is controlled by the vapor pressure gradient of the lung surface and adjacent atmosphere. As the air temperature rises in the burrow so does the air vapor pressure. Lawrence (1966) developed a relationship between vapor pressure, air temperature and relative humidity, and lethal limits for experimental mice (Microtus californicus). Lethal vapor pressures are not achieved until very high temperatures are reached. More field research is required to determine at what depths in the soil lethal conditions are reached for wildfires.

Short-term animal population effects

Immediately following fire, resident animal populations show a marked decrease in numbers. Cook (1959) studied rodent populations after a wildfire completely destroyed a grassland and brushland community near Berkeley, California, and found that there was an initial annihilation of the population. In the grassland the dominant species, including the western harvest mouse and meadow vole population densities equalled or exceeded the densities on adjacent unburned control plots. These mice feed on seeds and their population recoveries corresponded to the maximum seed production of the grasses. White-footed mice and house mice invaded the burned grassland where their densities were higher than normal for the first two years following fire.

In the burned brushland area there was a shift in small mammal species composition from brush dwelling mice to grass dwelling mice in accordance with the shift in habitat from brush to grass. The harvest mice and meadow voles populated the area the following summer and remained in higher density than the unburned brushland plot for the entire second year. There was no evidence to suggest the surviving mice emigrated to adjacent unburned areas but there was migration into the burned areas after the second year. The seed food source was not greatly reduced as a result of the fire which lead Cook to conclude that the recovery of small mammal populations on the burn was restricted in the first year due to lack of cover in both areas.

Habitat

Different wildlife species have different habitat requirements in the chaparral. Brush rabbits require heavy brush for cover whereas jackrabbits are more abundant in open brush stands. Valley quail, an important game species is in 2.5 times greater numbers in open brush than heavy brush (Biswell et al. 1952).

Working in a blue oak, digger pine, ceanothus, and interior live oak chaparral community of the western Sierra Nevada foothills, Lawrence (1966) felt that the decrease in vertebrate populations after fire was due to a greater predator population. Incidences of red-tailed hawks, Cooper hawks, sharpshinned hawks, sparrow hawks, great horned owls, and ravens increased for the first three years following fire. The lack of cover for prey was indicated as the reason for the increased predator populations. In most cases the food source was reduced significantly except that for seed eating species. Seed eating bird populations generally increase after chaparral fire. Other species like the valley quail decrease due to lack of cover and are replaced by grassland species such as the western meadowlark, morning dover, willow goldfinch and lark sparrow.

Food quality is the factor which limits most chaparral deer populations. Populations are highest where there is herbaceous forage for winter grazing and where the shrubs are highly preferred species. Availability of forage directly affects deer populations. Browse greater than 4 feet in height is often out of reach and goes unused by the deer. Closed, dense brush stands are used very little by deer due to the impenetrable nature of the vegetation.

Taber and Dasmann (1958) found that burning chaparral results in higher summer forage quality for one or two years due to the sprouting of shrub species. The average level of crude protein was found to be higher in burned areas. Some preferred brush species requre fire at periodic intervals to induce seed germination and maintain their status in the community. After fire there is a rise in deer population which declines over several years to its normal level. This rise is due to increased reproduction and decreased mortality. Increased hunter success in more open, recently burned areas often compensates for the temporary rise in deer numbers.

In summarizing many years of deer research at the Hopland Field Station in the northern California Coast Range Mountains, Longhurst (1976) stated that deer condition was only slightly improved by burning chaparral, although overall carrying capacity is increased. The oak woodland provides a better habitat and food supply for deer than the chaparral.

MANAGEMENT OF THE CALIFORNIA MEDITERRANEAN ECOSYSTEM

Historically, like much of the western United States, the California Mediterranean ecosystem was locally exploited by mining, timber and grazing interest groups. The present policies affecting management today and their rates of change are certainly altered for better or for worse because of man's calamities both perceived and real. Recalling the previously described boundaries both climatic and vegetational for the Mediterranean ecosystem in California, the most controversial wildland management issue today, involving the north coast redwood region, is outside those boundaries. However, memories of vegetation type conversion activities by grazing interests on marginal, transitional redwood sites still plague land managers today.

The primary management activities in the Californian Mediterranean ecosystem, outside those areas devoted to intensive agriculture, are rangeland improvement and maintenance, wildfire control, watershed protection, timber management, and recreation and wildlife ehancement. The discussion will concentrate on those activities that relate directly or incirectly to fire management.

Grazing by sheep, beef cattle or dairy cattle is the chief use of four of the nine Mediterranean plant communities described by Munz and Keck (1959), the Northern and Southern Oak Woodland, the Foothill Woodland and the Valley Grassland. A small part of the Chaparral plant community has likewise been utilized by livestock, following vegetation manipulation. Range improvement programs seek to enhance the quality and quantity of herbaceous forage per unit of land area.

On the open grassland sites, range improvement normally includes seeding of exotic legumes and perennial grasses such as subterranean clover (*Trifolium subterraneum*), rose clover (*Trifolium hirtum*), hardingrass (*Phalaris tuberosa*) and orchardgrass (*Dactylis glomerata*). Success in range seedings is enhanced by concurrent fertilization programs with phosphorus and sulfur on some soils. Given today's technology, seeding success is likely to result in production with higher quality forage.

Fire has not been a common management tool used on the open grassland of California. It may be used effectively to eradicate weeds temporarily, prior to an improvement program. Fire hazard in the dry summer period is certainly reduced on grazed grassland sites. When livestock prices are down the benefit from reduced fire hazard should be considered in a decision on grazing a particular area.

Range improvement on the three woodland vegetation types is attained by reducing the continuity of the woody plant canopy and again, the introduction of grasses and legumes, Methods used to reduce the canopy include mechanical, chemical and fire techniques. The practice of type conversion, the complete transformation from a woodland to a grassland vegetation, has been practiced in the past but is no longer desired except for fuel breaks. Cordwood is a potential byproduct if selective mechanical tree removal is economically feasible.

Chaparral, termed brush when perceived as a vegetation to be modified, has received the greatest attention by the range manager. On numerous sites brush has invaded onto more productive soils that are better suited to herbaceous forage production (Dodge 1975). Controlled or prescribed burning is the most frequently used method of management. Mechanical methods are normally used in pretreatment and they include ball and chain, disk, modified and smooth chans, straight dozer blade and brush rake clearing (Roby and Green 1976). Given the tremendous acreage of chaparral, range managers can be quite selective and modify only those sites that will yield the greatest benefits.

Fire suppression aspects of wildfire control have dominated fire management activity in the past. The full impact of fire exclusion policies are only now being realized. The theme of this symposium is founded on the problems created by man's ignorance of the fact that fire is a natural part of the functioning of a Mediterranean ecosystem. We are in the process of transforming our land management agencies function to fuels management realizing that the need for fire suppression will decline through time if fire is allowed back in the system.

Historically, forest protection was the thrust for fire suppression in California. Today, water and air pollution are further constraints on the judicial use of fire. Precedent and traditions are so strong that timber growers are still somewhat reluctant

to view fire as a part of the system. This is understandable since the fuel buildup under fire exclusion policies of the past pose the greatest threat to them.

The range livestock interests, as exemplified by their representatives on the Range Improvement Advisory Committee to the State Board of Forestry, are strong supporters of controlled burning for range improvement and range maintenance. However, the State Board of Forestry is reluctant to promote fire as a management tool because of the risks involved. Much of the burning proposed by the range livestock interests is on other than forested land, yet the agency responsible for fire control is the same for both land types. Agencies responsible for fuel management should realize the likely benefits of an interest group, like the range livestock interest group, that has an incentive to manage brush and at the same time accomplishes the purpose of the agency.

Proliferation of regulatory agencies further restricts the range livestock interests from burning. There is a high likelihood that burn days set by the California Department of Forestry occur on no-burn days set by the Air Resource Control Board and vice-versa. Risk of liability for damages due to controlled burn fire escapes are always a deterrent to more active burning programs by the range lvestock industry.

Alternate sources of water such as that provided by the California Water Plan and increasing values of sediment deposits as a resource have partially offset concerns for watershed protection in southern California. Many watersheds are so steep that little can be done to prevent erosion from the slopes; about all one can do is develop sediment catchments to reduce downstream destruction. The importance of woody plant root systems is well illustrated by the slope instability of Watershed II in the Hopland Field Station Study (Burgy and Papazafirion, 1971). Significant erosion protection results when riparian vegetation is maintained. More frequent, low intensity fires have a lower probability of producing non-wettable soils and therefore less erosion.

The Closed-Cone and Yellow Pine Forests are two types where the timber manager has great flexibility for fuel management. Annual fire fuel additions to the ground provide an ideal fuel source to carry light prescribed fires through a forest. Considerable knowledge exists for the application of fire to these types.

Active burning programs in the State and National Park systems should provide managers with the necessary information for setting prescriptions to achieve desired objectives in forest fuel management.

One of the more pressing issues faced by the timber manager today exists at that Transition Zone in the Sierra Nevada Mountains where black oak (Quercus kelloggii) is being removed and replaced by soft woods, especially pine. Oak acorn crops are an important seasonal food source for many wildlife species. Deer habitat is enhanced by the presence of black oak and early successional plants.

The recreation potential of the California Mediterranean ecosystem is virtually unlimited. The clean, open and parklike nature of a woody vegetation with natural fire is certainly more desirable than the impenetrable nature of decadent standing dead vegetation with excessive ground fuels. The public is learning to appreciate the presence of the charcoal remains of fuels. It is better to see some partially combusted fuel all of the time than all of the forest combusted some of the time.

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COMPARISON BETWEEN THE EFFECT OF PRESCRIBED FIRES AND WILD FIRES ON THE GLOBAL QUANTITATIVE EVOLUTION OF THE KERMES SCRUB OAK *(QUERCUS COCCIFERA L.)* GARRIGUES.[1]

Louis Trabaud [2]

Abstract: The global quantitative evolution of the kermes scrub oak garrigues is studied according to the action of prescribed fires or wildfires. Prescribed fires are set in an experimental area where their action is analysed according to frequencies and times of burnings. There is an important change in the vegetation structure as the burnings are more and more numerous: the herbaceous species tend to increase their phytomass at the expense of the woody species. In areas burned by wildfires, vegetation comes back similar to the one which preexisted before fire, in about six years, as, besides, for the prescribed fires if they are lit once only. The kermes scrub oak garrigues withstand well enough infrequent fires.

Key words: "prescribed fires" , "wildfires" , *Quercus coccifera* , "garrigues" , "southern France".

INTRODUCTION

The natural succession of the mediterranean vegetation is often disturbed by fire. In France, the most numerous and most harmful wildfires occur in the mediterranean area, an area which extends from the eastern Pyrénées, to the southern Alps, down to Corsica. Every year, about 50 000 hectares of natural vegetation are burnt by wildfires. Some years, this evaluation is higher, so, for example, in 1973, 71 610 hectares burnt.

Fire, natural or intentionally set, is therefore a past and present dynamic factor of prime importance in the succession of the vegetation, the scattering of the plants and their conquest for the soil.

Used for a long time by man to acquire new crop lands or to maintain in the same state other plots previously burnt, fire, associated with other anthropic factors, has broadly contributed to shape the natural landscape which is now the one of the mediterranean area.

Up to now, in France, the studies about the "fire" factor and its ecological action are not very numerous: RIBBE (1886, 1919), FLAHAULT (1924), BRAUN-BLANQUET (1935, 1936), LAURENT (1937), KORNAS (1959), KUHNHOLTZ-LORDAT (1938,1957, 1958). Generally, these authors only describe stages corresponding to vegetation types ; they give some informations about succession immediately following fire, and then compare the different stages to each other. But the results described are not data obtained from controlled or accurate experimental conditions nor observations done at regular dates after fire.

To bring a valuable answer in the knowledge of the future of the vegetation submitted to fire, we have studied this problem by doing continous observations with a network of permanent plots set up in Bas-Languedoc, and by experimental plots located in a kermes scrub oak *(Quercus coccifera* L.*)* garrigue. The choice for studying this plant community is justified by the large area occupied in southern France: more than 100 000 hectares, and also

[1]Presented at the Symposium on Environmental Consequences of Fire and Fuel Management in Mediterranean Ecosystems, Palo Alto, Calif. Aug. 1-5, 1977.

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by its position in the "classical" evolutive series, position due to the frequency of the fires.

What is the quantitative evolution of the vegetation of these kermes scrub oak garrigues submitted to prescribed fires set at definite times in the year and according to different rhythms, or burnt by wildfires in natural conditions?

QUANTITATIVE EVOLUTION OF THE KERMES SCRUB OAK GARRIGUES SUBMITTED TO PRESCRIBED FIRES

Localization of the experimental area

A complex experiment has been set up in a kermes scrub oak garrigue located on a hill called Puech-du-Mas-du-Juge (St Gély-du-Fesc township), about 10 km north of Montpellier. This locality has been the object of numerous previous studies: LONG *et al*, (1961, 1967), TRABAUD (1962), POISSONET (1966).

The initial stage was a garrigue of pyrophytic origin, about 18 years old (the last two very well know fire dates are: September 1943 and August 1951). The four main species, by decreasing frequency, are: *Quercus coccifera* 3/, *Brachypodium ramosum*, *Dorycnium suffruticosum*, *Rubia peregrina* (POISSONET, 1966). The shrubby layer, 0,5 to 1 m high, is formed almost exclusively by *Quercus coccifera* ; the grass layer is dominated by *Brachypodium ramosum*.

The experimental plots are located on the southwestern side of the hill ; the general slope of the ground, regular enough, is between 10 and 15 % ; the altitude is from 130 to 160 meters.

The climate, according to the EMBERGER'S classification (1942, 1971), belongs to the mediterranean humid type, variant with cool winters. The mean temperature is about 15°C ; the mean of the coldest month (January) equals 2.4° ; the mean of the hottest month (July) is 27.5° C ; the mean annual rainfall for ten years (1964-1973) is 1095 mm at St-Gély-du-Fesc. The season of the first pluviometric maximum is Autumn (A), the second maximum occurs in Spring (P), the lowest minimum is in Summer(E) and the second minimum in Winter (H), which gives a rhythm of APHE type.

The soils can be classified in the great group of calcimorph soils (brown, calcareous brown soils and rendzinas) formed on Eocene compact limestone or on various light (terra - rossa) ; they have generally an irregular depth, but always shallow (10-15 cm) ; they are pebbly with a fine medium texture, a pH near the neutral point (6.5 to 7.5) and a calcic mull.

These lands were cultivated a long time ago because numerous traces of dry-stone walls still today testify this past. Abandoned, these lands have evolved towards a garrigue due to repeated fires set, deliberately or not, by sheepherds to regenerate the pastures and to open the vegetation to permit the passage of the flocks.

Description of the experimental design

Methodology to estimate the plant succession

The methods to study the succession of the vegetation must allow to point out and record the successive changes happened through the years for different stages of vegetation invading the bare ground.

The techniques for this kind of study are the following:

- permanent lines (quadrat points, presence of species under consecutive segments: LONG, 1957, 1958 ; GODRON, 1966 ; DAGET and POISSONET, 1971) ;
- permanent square plots (density, cover, vigor: BRAUN-BLANQUET, 1972) ;
- photography and cartography of plots.

Only simple and inexpensive tools normally used for these kinds of studies are required, such as posts, frames and measuring tapes ; these apparatus permit to follow the progressive occupation of the stand by the plants which reoccupy the ground after fire.

The evolution of the vegetation can go towards four directions: (1) a deeper degradation of what the vegetal cover before fire, (2) a recycling to the previous vegetation, after a certain lapse of time, and a few intermediate stages, (3) a recycling to the previous vegetation without intermediate stage, (4) a progressive succession towards a high garrigue, different from the former garrigue (improbable eventually).

Before giving a detailed account of the

3/The names of the species are those given in "Les quatre flores de France". P. FOURNIER, 1961, Le Chevallier Ed., 405 p.

design, it is necessary to emphasize that the controlled fire experiment is one of several experiments undertaken at the same experimental area, all part of a larger project to study changes occurring in a vegetation submitted to different treatments.

During the initial period, before beginning the treatments, a vegetation inventory of each basic 50 square meters plot (10 x 5m) was made. To do this, permanent vegetation study lines were set up in each plot. Every 10 cm, observations are made along the line according to a precise protocol (TRABAUD, 1974). Afterwards, in spring every year, such measurements are repeated. So, we have a precise knowledge, both in space and time, of the whole vegetation (quantity and plant cover) and of its evolution, before and after the treatments and according to them.

Burning treatments

The fires are set at two precise times in the year to determine if the seasonal conditions which affect the plant phenology act together, and in what way, with the fire force, and if these conditions modify the future behaviour of the different species, and the equilibrium of the vegetation.

Times of burning

To determine the burning dates, we have taken as criterion, some mean phenological stages of the population of *Quercus coccifera* this one being the principal species.

First case: the first burn is set at the beginning of the *Quercus coccifera* flowering, when vegetative growth has really started, since the buds have already developed the first annual shoots and emitted the young leaves. The kermes scrub oak is then in a turgid state, at the maximum photosynthetic stage (ascending sap, full vegetative activity), usually at the end of May or the beginning of June.

Second case: for the second burning period we have chosen a time at the beginning of fall, when the vegetation appears to be at rest (reduced photosynthetic activity, ripening of twigs), always at the beginning of September.

Periodicity of the fires

The chosen burning periodicity is: a fire every two years for one group of plots, a fire every three years for another group, and a fire every six years for the third group ; this, to determine if the fire frequency has an effect, and if so, which one, upon the vegetation.

Therefore, the experimental design allows three treatments at two burning times, i.e.:

- No burning

(T) control plots not burnt

- Seasonal burning times

(P) burning at the end of spring or beginning of summer (first case)

(A) fall burning (second case)

- Fire frequency

(1) plots burned every six years

(2) plots burned every three years (two fires in six years)

(3) plots burned every two years (three fires in six years)

Six replicates have been established for every treatment, i.e. 42 basic plots on the whole. The treatment observations and measurements are made on the central strip of each plot.

Kinds of observations and measurements

a) before and after fire, the observations are made on:
- the floristic composition of each plot ;
- readings of permanent lines to determine the frequency, the quantity, the cover of the species and the vegetation structure ;
soil samples are taken to know the evolution of the edaphic elements from the shallow layers ;

b) during the fires the observations are about:
- the meteorological conditions at the time of burning ;
- the rate of spread of the fire ;
- the temperatures.

All these observations facilitate the understanding of the fire mechanism and behavior.

Exemple of the analysis of the results

Given the number of the observations collected and the measurements carried out during the seven years (1969-1975) of the study, we will examine only the results done by all the "contacts" without floristic distinction. Every part of an individual from a species which is located on the observation vertical and which touches along the generating line made by the needle is considered as a "contact". The sum of all the contacts can be considered, at a few approximation, as a

relative expression of the quantity of a species, or all of the species, which constitute the community (DAGET and POISSONET, 1971, 1974).

The experimental design was established to analyse statistically the gathered data ; because it is necessary to know if the oberved differences are important enough to be significant and therefore attribute them to the treatments, or, on the contrary, if they remain in the order of the aleatory fluctuations. To test the differences which can appear between the different treatments along the years or every years between all the treatments we used two tests based on the ranges (PEARSON and HARTLEY, 1958 ; SNEDECOR and COCHRANE, 1971).

The first test corresponds to a variance analysis, it is the "Studentized range test" which uses the ratio:

$q = (\bar{x}\ max - \bar{x}\ min)\ c\ \sqrt{n}\ /\ \bar{\omega}n$ where

$\bar{x}\ max - \bar{x}\ min$ corresponds to the differnce between the highest and the lowest means,

$\underline{c}$ is the scale factor (corrective term) given by a table,

$\underline{n}$ is the sample size,

$\bar{\omega}n$ is the mean value of all the ranges, i.e. the mean of all the differences between the highest and the lowest value of every sample series.

The use of this test needs two tables: one which gives the degrees of freedom according to the sample size and the number of samples, the other which gives the significance level.

The second test is a single tail test $\underline{t'}$ based on the range, which allows to test the difference between means compared two by two:

$$t' = \frac{\Delta\omega/\bar{\omega}n\ \sqrt{2}}{c\sqrt{n}}$$

where $\Delta\omega$ is the significant difference beyond which two means are significantly different at 5 %.

Let us take an example. The plots which have not been burned constitute the control treatment (table 1). Applying the Studentized range test:

$(700.3 - 488.8)\ 2.56\ \sqrt{6}\ /\ 256.28 = 5.17$
for k = 7, number of samples (seven years), and n = 6, sample size (six replicates), the first statistical tables gives $\underline{\nu}$ degrees of freedom equal to 31.5 and c = 2.56.

Plots \ Years	1969	1970	1971	1972	1973	1974	1975	Mean
T_1	625	612	465	638	648	784	449	603.0
T_2	419	522	579	450	453	838	628	555.6
T_3	539	701	483	667	587	758	561	615.1
T_4	456	544	785	583	708	628	361	580.7
T_5	541	486	729	474	607	590	453	554.3
T_6	570	573	430	419	485	594	481	507.4
Mean	525.0	564.7	578.5	538.5	581.3	700.3	488.8	569.3
range	206	215	355	248	255	248	267	256.28

Table 1. Number of total contacts by plot and by year. Control treatment.

The probability for 5 % is 4.46 and for 1 %, 5.40, hence the difference between the years,for this treatment is significant at 5 % level. Now, it is necessary to search which year produces this significance.

Let us search for $\Delta\omega$; t'for the number of degrees of freedom mentionned above is equal to 1.697 ;

$$1.697 = \frac{\Delta\omega}{\dfrac{256.28\sqrt{2}}{2.56\sqrt{6}}} \qquad \text{let } \Delta\omega = 97.8$$

Among the seven years, only 1974 presents a higher difference than 97.8 ; therefore the contacts done by the vegetation in 1974 are significantly more numerous than those of the other years.

This difference is due to the observation period. In fact, all the observations every year were done during April, except in 1974 where observations were carried out in May. Now, in May, the kermes scruboak, and the whole vegetation, are at the period of maximum activity. The new leaves have appeared, the floriferous spikes have grown, what increase the number of contacts. On the other hand, in April, the vegetation is still dormant, some leaves have dried out, other have fallen down during the Winter ; so that, by that time of the year, the vegetation is less dense ; if, in 1974, the observation period had been in April, probably there would not be a significant difference between the successive years.

All the other treatments were analysed in the same way. The quantity of the vegetation in 1974 is higher than the one of the other years. Moreover, the vegetation of each year following the burnings differs significantly from the one of the other years: immediatly after fire, the sum of all the contacts is low (table 2).

Evolution of the quantity of the vegetation

As the control treatment, except for 1974 for the reasons given above, does not present any difference along the years, we can consider it as constant during the duration of the experiment and compare with it the other treatments.

During the two first years of the experimentation, the different treatments grouped two by two (1 P and 1 A, 2 P and 1 A, 3 P and 3 A) have all the same evolution (fig. 1).

Taking into account only the treatments 1 P and 1 A joined together (i.e. one fire in spring or autumn in a six year cycle) the corresponding vegetations tend, along the years,

Years / Treatments	1969	1970	1971	1972	1973	1974	1975
T	525.0	564.7	578.5	538.5	581.3	700.3	488.8
1P	617.8 ⁙	148.2	403.0	478.7	486.0	695.7	415.0
2P	478.7 ⁙	225.7	361.5	459.3 ⁙	202.8	536.0	355.0
3P	566.7 ⁙	219.2	394.2 ⁙	170.7	327.0 ⁙	328.5	218.5
1A	558.7 ⁙	55.0	300.2	434.0	459.7	680.3	306.3
2A	540.2 ⁙	68.8	343.7	400.2 ⁙	96.0	565.2	300.0
3A	488.8 ⁙	60.3	297.5 ⁙	157.3	325.2 ⁙	242.0	191.0

Table 2. Evolution of the mean number of contacts by treatments along the years.

⁙ burnings

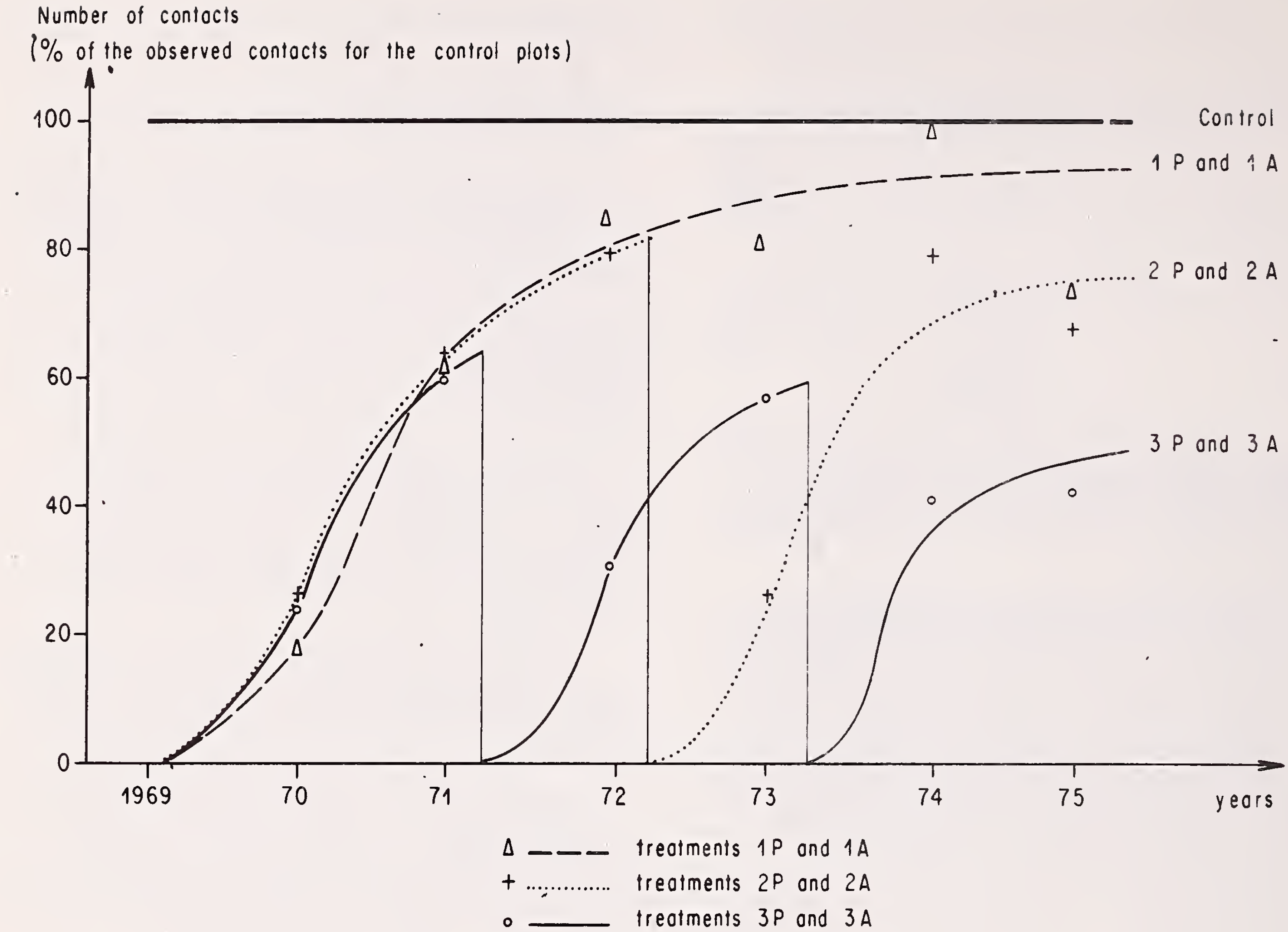

Fig. 1 Evolution of the ratio: $\frac{\text{mean number of contacts by treatment}}{\text{mean number of contacts for the control plots}} \times 100$

according to the frequencies of the burnings along years

to draw near to the vegetation not burned. Five to six years after fire, the once burned vegetation (90 % of the control plots vegetation). By that time, the treatments T, 1 P and 1 A do not differ significantly between them.

After a second burning the vegetation presents the same evolutive kind for the quantitative reconstitution than for the first burning ; yet, a "limit" seems to appear, it would be lower (70 %) than in the case for one fire. For the vegetation of the treatments 3 P and 3 A burned at the time of the second burning this limit is lower (60 %) than the one for the vegetation of the treatment 2 P and 2 A at the time of their second burning. This peculiarity must be due to the fact that the lapse of time between the successive fires is only two years for the treatments 3 P and 3 A. The one year supplementary lapse of time before the second burning for the treatments 2 P and 2 A allows a more important quantitative vegetation increase and allows it a better withstanding of the stress created by the second coming of the flames.

At the third burning (3 P and 3 A) the limit for the number of contacts reaches only 50 % of the one of the unburned vegetation. After each burning and according to the fire frequency the total vegetation quantity decreases. On the other hand, the vegetation reconstitution is more and more rapid ; the relative differences of the progressive decreases (Δ) between the vegetation quantities become smaller according to the successive burning (fig. 2). What permits to think that burned vegetation will reach a new quantitative stage in equilibrium with the successive burnings after the fourth or fifth burning. If fire action was stopped vegetation would take as longer time to reach the initial stage

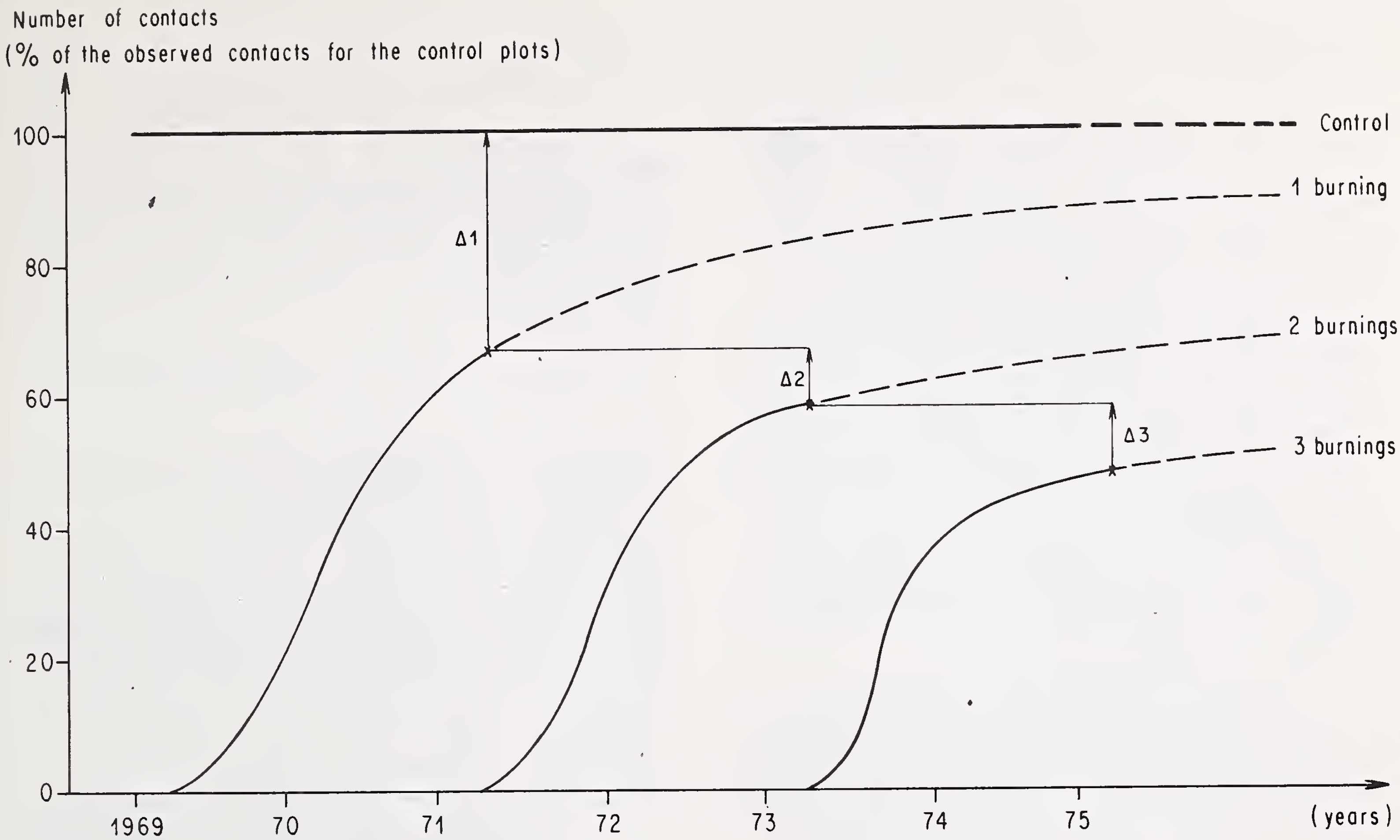

Fig. 2 Progressive decrease of the relative quantity of the vegetation according to the frequency of the burnings

as it was burned more frequently.

Moreover, the lapses of time the vegetation of each treatment takes to reach its own limit are shorter and shorter according to the burning frequency: five to six years are necessary for one fire, four years for the second fire, and three years for the third fire (fig. 1 and 2).

The decreases of the vegetation quantity is particulary the fact of the woody species, which give sprouts less and less longer ; therefore there are less leaves. On the other hand, the number of contacts of the herbaceous species tends to increase along years.

The decrease of the number of contacts for the woody species is particularly characteristic for the layers higher than 50 cm ; whereas, the number of contacts of the layers lower than 50 cm for the frequently burned vegetation becomes bigger than the one of the unburned vegetation. This is due, largely, to the herbaceous species, their optimal development occurring always in the layers lower than 50 cm, the coming of the flame does not diminish their number of contacts, but would rather tend to increase it.

QUANTITATIVE EVOLUTION OF THE KERMES SCRUB OAK GARRIGUES AFTER WILDFIRES.

Situation of the releves

To follow the evolution, as qualitative as quantitative, of kermes scrub oak garrigues burned by wildfires, we have set up a series of permanent plots in this type of plant community. These plots are scattered all over the place in the eastern part of the Herault County (50 Km around Montpellier). They are located in burned areas from which the fire dates are well known. So, it is possible to

follow up the evolution year after year and to know the vegetation state some years after fire.

The situation and the choice for the sites of the releves have been possible owing to the collaboration with the "Services d'Incendies et de Secours du département de l'Hérault". These ones have authorized us to examine all the fire reports since 1962. This work permitted to draw up a map of the burned areas in the county and to know precisely the dates for all the recorded wildfires. After a reconnaissance in the fields of the burned areas, the criteria for the choice of the study areas were the apparent vegetation homogeneity and its agreement with the characters of the Cocciferetum community as defined by BRAUN-BLANQUET *et al.* (1951) ; as for the garrigue submitted to prescribed fires, all the kermes scrub oak garrigues studied here belong to the "sub-association" Brachypodietosum which is linked with a hard calcareous substrate, generally very dry.

Though these garrigues agree with the criterion given here above, the structures and the phytomasses are very different between each site ; probably due to their past history and the biological potentialities of the substrate.

Methods used for the observations

The observation site consists of a permanent line from which the reference posts are cemented in the ground, and of a 100 m^2 phytoecological releve located on both sides of the observation line. These sites are regularly observed.

Consideration of the quantitative results

Because of the structure, we have distinguished the garrigues where the kermes scrub oak cover alone reached or went beyond 85 % at the end of three years, from the garrigues where the kermes scrub oak cover, due to soil nature the most often, was less than 85 % after three years. The most part of these latter have a number of contacts lower than the one of the other garrigues ; which would tend to prove the kermes scrub oak alone constitutes the greatest part of the whole plant mass.

Evolution of the vegetation quantity

Immediately after fire, the vegetation shoots up again vigorously (fig. 3). One month

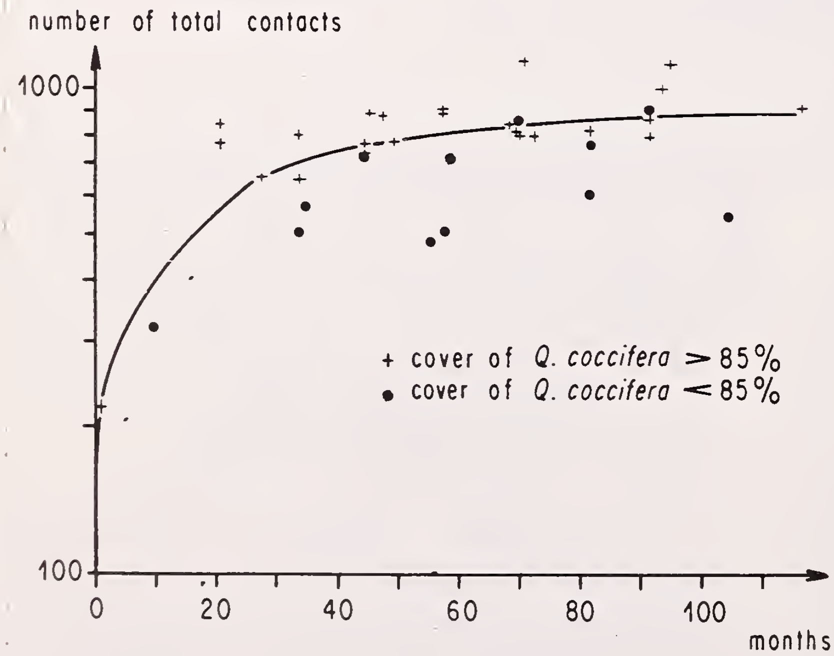

Fig. 3 Increase of the number of contacts in the kermes scruboak garrigues during months following fire

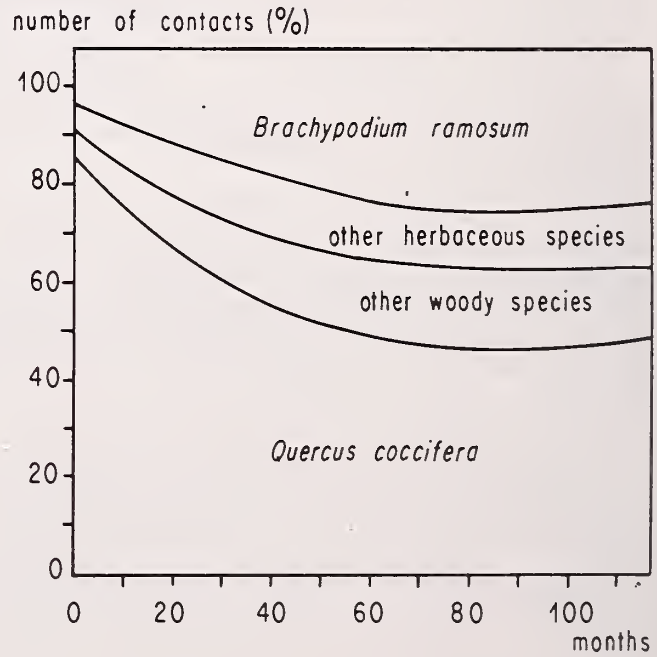

Fig. 4 Evolution of the relative proportions of the number of contacts of different kinds of plants in the kermes scruboak garrigues following fire along months

after fire, there are numerous sprouts of kermes scrub oak ; it is one of the first species to sprout from stumps (TRABAUD, 1974). Then, progressively along years after fire, there is an increase of the number of contacts as for the woody as for the herbaceous species. During the first months, the woody species sprout up again quicker than the herbaceous. These are really sprouts, because in kermes scrub oak garrigues, a very few species appear by seeds (TRABAUD, 1970) and the annuals do not practically exist. There is no intermediate stage, the kermes scrub oak and its associates sprout immediately after fire.

Later on, though the number of contacts continues to increase regularly, the quantity of plant material produced increases less and less. Four to five years (50 to 60 months) after fire, the number of contacts does not go up practically more. This phenomenon is the same as the one observed for the experimental plots burned once only ; but, it often appears sooner. The quickest increase takes place during the two first years.

During the first months after fire, kermes scrub oak is among the first species to colonize the ground ; it constitutes the greatest part of the vegetation (fig. 4). Its sprouts bear many little leaves. Then, progressively, as the sprouts take longer the number of leaves will grown but not so many proportionally to the length of the sprouts. In the same time, the other species appear, they also give more and more numerous shoots. As the growth of the garrigue becomes steady, the proportion of the kermes scrub oak diminishes, and so in spite of the increase of the number of its contacts, then remains at the level of 50 %. Contrary to this kermes scrub oak proportional decrease the other woody species will increase up to reach about 15 % of the total vegetation quantity, later on, this proportion won't nearly be developped any more.

The *Brachypodium ramosum* relative quantity increases during the first years. When the garrigues reach their equilibrium, i.e. at the end of five years, *Brachypodium ramosum* constitutes 25 % of the whole vegetation. Here too, later on, this proportion will not nearly change any more.

The other herbaceous species, which have a number of contacts equal to the ones of *Brachypodium* during the first months after fire, will decrease progressively to constitute only 10 % of the contacts.

At the end of ten years after the coming of fire, it would seem there will be an increase of the quantity of kermes scrub oak (fig. 4) at the expense of the other woody species. This phenomenon would be the reverse for *Brachypodium ramosum*, the tendency of which would be towards a light decrease of the quantity.

Evolution of the horizontal structure

If instead of the observation of all the contacts done by the different species, every species is recorded once only at each point of observation along the line, even the species does several contacts, the number of points under which a species is recorded gives the "specific frequency" (GODRON, 1968 ; DAGET et POISSONET, 1971, 1974). If this frequency is brought up to the percentage of the number of points of observations along the line, we obtain the species "centesimal frequency" which constitutes an appraisal of the species cover (GODRON, 1968).

In many kermes scrub oak garrigues, ground occupation by vegetation is very quick because ten months after wildfire the plant cover is higher than 90 % (fig. 5a). After thirty months, vegetation covers more than 95 % of the burned area and it will continue up to occupy 99 % to 100 % of the whole fired area. As for the vegetation quantity, the garrigues where kermes scrub oak does not occupy more than 85 % of the ground surface at the end of three years after fire present a total cover less important than the other kind of garrigues ; for example, ten months after fire, the plant cover is only 55 % and even 35 %.

To compare, figure 5 b shows also the plant cover in the experimental plots where there was only one fire set either in Spring, or in Autumn ; these treatments are very similar to the wildfire action, because accidentally fires rarely occur every two or every three years on the same places. As for the sites burned by wildfires, thirty months after fire, the plant cover reaches 95 %, whatever the times of burnings. Around the fortieth month, the cover of burned vegetation is identical with the one of the unburned vegetation.

DISCUSSION AND CONCLUSION

Immediately after fire, there is a rapid growth of the vegetation. If we consider the number of the total contacts which is an estimate of the vegetation quantity done by all the species which constitute the plant community, we ascertain that, in the experimental plots as well as in the sites burned by wildfires,

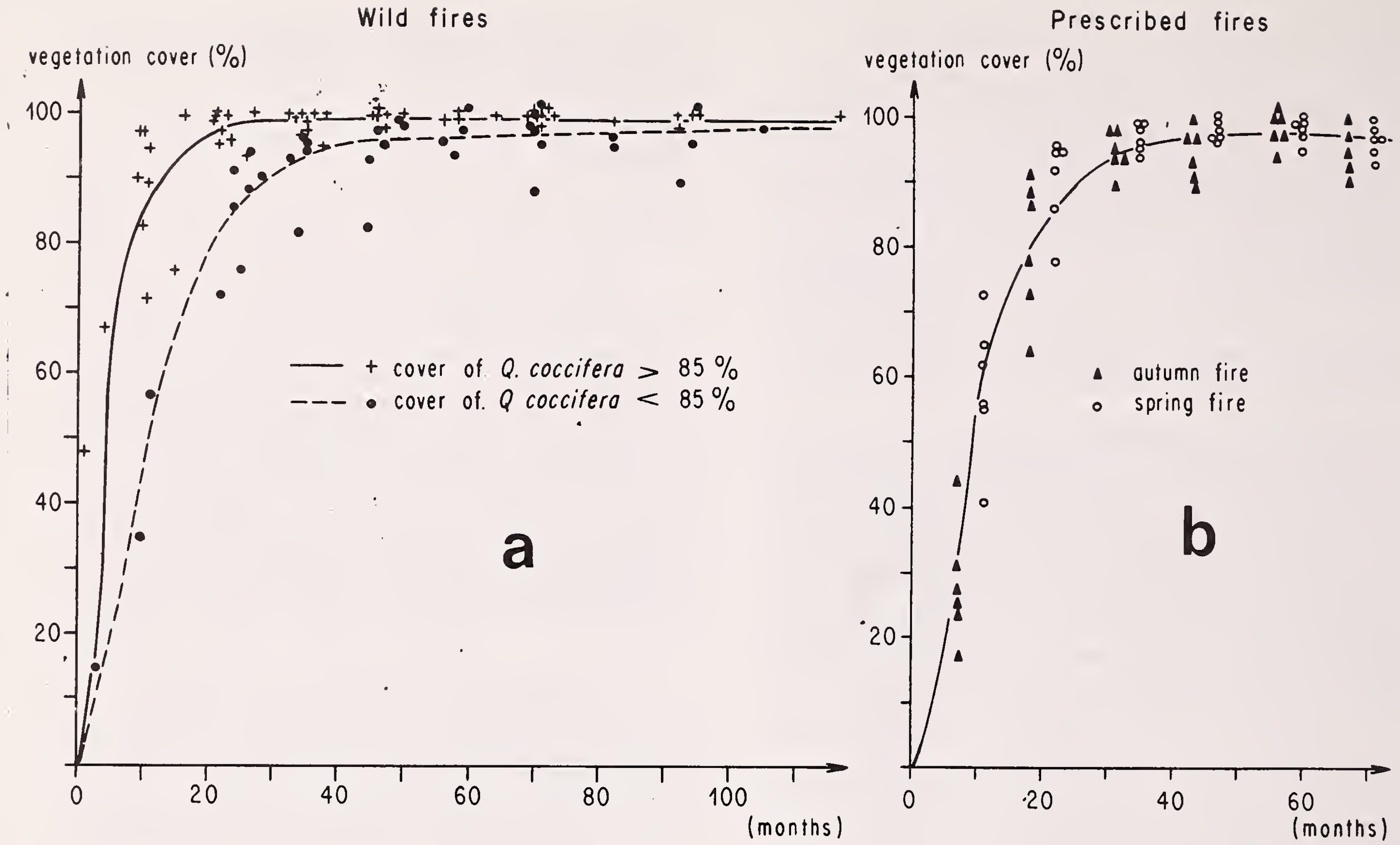

Fig. 5 Total vegetation cover in Kermes scrub oak garrigues following fire

vegetation recovers quickly: 200 contacts on a site one month after fire. We have observed in many places sprouts of kermes scrub oak fifteen days after fire ; and two months later some of these sprouts reached 50 cm high. After this very rapid start, the oak stops its growth, mainly during the winter period when it is in rest condition. The new shoots will appear only during the following spring.

Later on, around the fourth or fifth year, vegetation quantity reaches its "limit" for the experimental plots (fig. 1, treatments 1 P and 1 A) as for the sites burned by wildfires (fig. 3).

The evolution of the total vegetation cover corroborates this tendency. Vegetation tends cover very quickly the whole area occupying the bare surface before to grow up, because three years after fire, in the sites burned by wildfires as well as in the experimental plots the vegetation cover reaches 95 %. Though partially simultaneous, it is only after this occupation of the superficial horizontal space that vegetation will reoccupy the horizontal an vertical aerial space. Then vegetation will grow higher and denser to reach the original state.

On the other hand, if fire is set more frequently than in the normal cycle (about at least every five or six years for some areas from which we know very well the story by fire reports), it is the case for the plots burned experimentally, the tendency towards the initial state is slowed down. The total number of contacts (and consequently the phytomass) is less important ; even it becomes lower. This decrease is due to a diminution of the number of contacts done by the woody species. All their stems above ground are frequently burned and they have no time to sprout. On the other hand, the herbaceous species withstand better to the flame coming, even they tend to increase their number of contacts. Likewise, the times of burnings have an effect upon the species ; the herbaceous are the most abundant in the plots burned in autumn.

Besides, in spite of the burning frequencies, the garrigue burned experimentally has remained floristically a kermes scrub oak garrigue (Cocciferetum, Br-Bl, 1924). Of course,

new species appear, mainly annuals, but they disappear as quickly as they have appeared, probably due to interspecific competition when the fire influence lessens (TRABAUD, 1970, 1974). There is also a disappearance of some species, but the floristic composition on the whole remains the same, there is only a change in the structure, a disappearance of the upper layers (above 50 cm) which were occupied by woody species.

The current kermes scrub oak garrigues withstand well enough fires. If they are not submitted too frequently to fires kermes scrub oak garrigues recover quickly their original sight, as physiognomic as floristic. At the end of two years after fire, the tendency towards the original garrigue is evident ; at the end of five years the differences between a burned and an unburned garrigue are very difficult to see. Only charred stems emerging out of the vegetation mass testify of the fire coming.

The upsettings of the equilibrium created by fires do not hinder vegetation to reach again a relatively "constant" stage, which is, nevertheless, really difficult to qualify as "stable". All depends, in fact, on the scale with which time is considered. During the years of observations, vegetation looks very stable because it comes back quickly enough to a state which seems constant. It is better to qualify this phenomenon as vegetation "elasticity".

At the end of twenty to thirty years, the kermes scrub oak garrigues have a tendency to degenerate ; they present signs of senescence : dead woods, stems without leaves, the new produced leaves take only the place of the old ones which fall down ; there is no increase of the phytomass, only a substitution. Fire is necessary to regenerate the kermes scrub oak. But, how can we give an age to these garrigues ? They look only ten or fifteen years old (time generally after fire), but the "Oak" individuals, owing to the fact that their root systems have allowed then to survive all those events, as they have been burned, they have resprouted, they have been burned again, etc, during several cycles, they can have a very good old age, difficult to evaluate. If they are not rejuvenated by fire, they tend to degenerate and disappear. Then the vegetation evolves towards a forest owing to high woody species which will settle down ineluctablely (*Pinus halepensis, Juniperus sp., Quercus ilex, Q. lanuginosa, etc.*) ; this natural afforestation is more or less rapid according to the proximity of seed-bearers.

As a matter of fact, the kermes scrub oak garrigues represent only a stationary state included in the Mediterranean phytocenoses series.

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LAND USE PLANNING OF THE FRENCH MEDITERRANEAN REGION [1/]

Jane M.S. Robertson[2/]

Abstract : Land use planning in France is faced with a fire problem of socio-economic origin resulting from the abandon of rural agriculture and the massive increase in tourism. The French authorities are taking the following steps : control of real estate transactions, maintenance and renovation of traditional agriculture and restoration of the social and ecological role of Mediterranean natural areas. The paper describes what practical measures have already been undertaken and what is envisaged for future land use planning.

Key words : French land use planning, fire causes.

INTRODUCTION

When one considers land use planning in the Mediterranean region of France which is extremely prone to forest [3/] fires, one realizes that until very recently, there has been no a actual land use planning related to the forest fire problem.

This is perhaps due to a lack of communication amongst the administrations dealing with forestry, agriculture, land development and fire control etc, and the fact that most brush and forest lands are privately owned, subdivided into extremely small lots sometimes down to 10 square meters.

As is discussed below, the forest fire problem stems from socio-economic difficulties resulting from rural depopulation in the last 30 or 40 years.

In view of the increasing amount of damage caused by forest fires, from 1962 onwards the Ministry of Agriculture, the Ministry of the Interior and other administrations decided to concentrate some efforts into forest fire control. The law of 12 July 1966 for Mediterranean forest protection and reconstitution begun a whole series of prevention and suppression activities. In 1971 the Interministerial Mission was created for the Protection and Management of Mediterranean natural areas (Mission Interministérielle, 1975 c).

I am doing research in collaboration with this Interministerial Mission and find that their activities, although as yet limited, correspond to the American concepts of land-use planning and fire management.

The appendix shows a simplistic flow chart illustrating the connections of this Mission and the different administrations involved in forest management and fire control.

The Interministerial Mission is not a directive body but is responsible for the coordination of forest fire control activities and for the definition of a programme for protection of natural areas and for upgrading brush, where possible, into some kind of uncommercial or commercial forest.

[1/] Presented at the Symposium on Environmental consequences of Fire and Fuel Mangement in Mediterranean Ecosystems, Palo Alto, Calif. Aug 1-5, 1977

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[3/] "Forest" fires are meant here in a general sense for brush and forest fires. In France, the term "maquis" usually refers to brush vegetation on acidic soil ; "garrigue" refers to brush vegetation on calcareous soil. It is often difficult however, to make a distinction between this brush and the "forest" proper.

The Mission also looks into urban development, housing schemes and agricultural projects which affect open natural areas (Mission Interministérielle, 1975 b).

In order to understand what measures have been undertaken and have been envisaged by the Interministerial Mission, I think it is necessary to give a background summary of land use history in Mediterranean France, giving the modern trends in land use and some major causes of forest fires.

LAND USE HISTORY

Up till the first and second world wars, the rural population was relatively high and the land was intensively used. This applies to lowland and mountainous areas such as in Corsica where the mountains reach over 6000 feet.

The sloping land was cultivated in terraces with vineyards, cereals, vegetables, orchards and abundant olive groves. Sweet chestnut trees (Castania sativa) were planted on the deeper acidic soils and provided shade, soil protection, stakes for fencing and chestnuts for flour and fodder. Pigs were often to be found searching for chestnuts in these woods, and also for acorns under the Holm oak (Quercus ilex) trees. These oaks were generally coppiced providing wood for timber, charcoal and heating and cooking purposes. Cork oaks (Q. suber), growing only on acidic soils, were stripped regularly for their valuable bark. The Aleppo pines (Pinus halepensis) were used for wood and resin and more recently, the introduced maritime pine (Pinus pinaster) provided a quick-growing source of wood until its populations were decimated by the Matsococcus disease.

This systematic thinning and herbaceous foraging meant that the woods were kept clear of combustible undergrowth.

Fire was used also to burn weeds and stubble in the fields (Kuhnholtz-Lordat, 1958). This form of prescribed fire called "petit feu" (literally "small fire") is rarely used at present as there are few people who are competant enough to know under what conditions a controlled burn is possible (Chautrand, 1975).

Shepherds with flocks of sheep, goats and cattle used the brush and fallow land on the lowlands and foothills for winter pasture and went with their animals to alpine meadows in the mountains during the summer. This transhumance was once very common and to some extent is still practised today.

As a result of this intensive land use, there was perhaps overgrazing and land mismanagement causing soil impoverishment and soil erosion, but wildfires were neither as frequent nor as vast as they are at the present time. The land was broken up sufficiently to prevent fires sweeping from one catchment basin to another, and the local population was always present to combat a fire that would destroy the crops. The forest fire situation has only constituted a real problem in the last 30 years.

MODERN TENDANCIES IN LAND USE

Since the Second World War, there has been a marked depopulation of rural areas, areas such as the back country of the Languedoc and Provence regions and also in Corsica. Whole villages have been abandoned as the local population left their land following the exodus towards the towns in search of a regular salary.

As a result, the fields and terraces have been abandoned and have been invaded by weeds and then brush "maquis" or "garrigue". Wells have been filled in and primitive but effective irrigation systems have fallen to ruin. This formally cultivated land no longer provides a barrier to the spread of wildfires.

The oaks, chestnuts and olive trees have grown old and senescent. Pine trees have regenerated and spread with fires, but being so combustible and given the high frequency of fire occurrence, are often burnt before they reach maturity.

In contrast to this rural depopulation, the increase in tourism has been quite spectacular. This started first along the coastal area on the famous Riviera (Côte d'Azur) which is now infamous for its concrete, traffic problems and air pollution on a scale familier to the inhabitants of the Los Angeles area.

The Languedoc-Roussillon coast to the West of the Rhone Delta has been a subject of recent touristic development.

Towns have expanded incredibly with housing schemes for residences and holiday homes stretching around their perimeters. This is true not only on the coast, but also in the interior, where formally relatively small towns have grown important. Montpellier for example, a university town, has become a centre for light industries in the last 20 years ; Aix-en-Provence, originally a Roman spa, has become a pole for cultural and artistic activities.

This town expansion has meant that there increasing pressure on agricultural land and on hunting areas for housing development. This causes a lot of social unrest within the resident population which gives rise to many arson fires. It is difficult to prove but it is probably true that for example rivalry between hunting organizations or quarrels between landowners often result in the deliberate setting of fire to brush and forest. There is also suspicion that housing developers occasionally set fire to private land in order to incite a sale.

In Corsica, the shepherds are often at the origin of some of the big "maquis" fires. There are several reasons for this, but it seems to stem from a change in the shepherds' attitude to the "maquis". Today, they do not care for the land unless it is burnt giving an autumn "flush" of greenery. By tradition, fires are set on windy days to give a fast "cool" fire that will not destroy the seeds of forage plants (Degos, 1975). Since there are no longer fields and orchards to act as barriers to these fires, they spread very rapidly.

The law tries to sanction these actions by prohibiting or requiring legal permission for the shepherd to burn. This creates difficulties which the shepherd circumnavigates by setting fire clandestinely by some ingenious "delayed ignition" mechanism, giving him time to establish a solid alibi. It may be necessary to add that the shepherd is only a tenant and not a land owner, so the consequences of such a fire are of relative unimportance to him.

In addition to all these arson fires, there are also many fires set accidently by tourists and children, and "run-away" fires from stubble or rubbish burning. This latter is noted especially in small towns where the summer influx of tourists causes a waste collection and disposal problem.

The rubbish is too often simply burned in the local open dump on the periphery of the town, creating a source of firebrands next to the natural vegetation.

I think it is apparent from this brief description of the forest fire problem in Mediterranean France that any land-use planning must take into account these socio-economic problems which are at the root of many of the big destructive fires. One must therefore try to create an integrated multipurpose land use pattern which satisfies tourists, developers, farmers, hunters, shepherds etc... (Mission Interministérielle, 1975a).

POSSIBLE SOLUTIONS

The Interminsterial Mission is attempting to modify present agricultural and urban practices in a way that they help solve the forest fire problem instead of aggravating it further.

To do this, three basic steps are considered

a) control of real estate transactions,
b) maintenance and renovation of traditional Mediterranean agriculture,
c) restoration of the social and ecological role of the Mediterranean natural areas (Mission Interministérielle, 1975d).

a) Control of real estate transactions.

It is necessary to coordinate land acquisition by the State and by communities and to find the best use of these natural areas. The unification of agricultural and forested land belonging to a multitude of small landowners is also indispensable. This is a very difficult process and is slowly being realized through Forestry and Agricultural Real Estate Associations (Associations Foncières Forestières et Agricoles).

The Interministerial Mission has undertaken a special study on the housing development problem in Mediterranean natural areas (Racine, 1975). At present, there is a tendency that permanent and holiday residences are constructed right into the forest, often in old Holm oak (Quercus ilex) coppice. From an ecological point of view, if each housing lot is no larger than 1 hectare (2.5 acres), one can consider that the forest is virtually condemned. Even if individual lots are bigger, the trees and their roots are damaged by construction. In addition, the undergrowth is by law cleared for 50 m around each house. This means that there are important ecological consequences : for example there is no possibility for natural tree regeneration and the brush understorey is replaced by a low flashy vegetation which easily carries fires into uncleared forest.

In order to render the houses as isolated as possible, they are often built in a denditric road pattern with a series of dead-ends. In the event of a fire, this pattern neither favours the evacuation of residents nor the access for firemen.

It is therefore necessary to construct houses in a manner which will reduce the impact on the natural vegetation and facilitate fire control.

This could be done by reducing the size of gardens and grouping houses together on open cleared areas on hillslopes, hilltops or plateau edges in a way reminiscent of traditional villages. These residential areas could be linked by wide fuel-breaks with cultivated fields and landscaped park-like zones for recreation. One major problem would be the difficulty of finding sites where the soil is suitable for agriculture and trees and yet be strategically situated for fire control purposes.

However, the grouping of houses with cleared and maintained "safety zones" may win favour, especially as the surface area required for housing development is much reduced, lowering initial costs.

b) Maintenance and renovation of traditional Mediterranean agriculture.

This is very important for it is necessary to have people resident in rural areas to maintain fire control constructions. This has been tried in two ways.

A positive step has been taken by the creation of 9 units of forest-firemen ("sapeurs forestiers") each of 24 men. These units are made up of local agricultural workers who live in rural villages. For about nine months of the year they construct and maintain pathways, fuel-breaks, "safety-belts" around villages and water points etc. In the summer seasons they are active on fire patrol, are ready to begin first attack and also to apprehend any carelessness with fire. At present 60 % of their salary is paid by the State, 40 % by local communities. This initiative is not without sociological significance for , assured of a steady source of income, families are now setting or remaining in isolated villages.

Another step towards rural renovation has been attempted through pasture improvement. Corsica was chosen as a study area because of its notorious fire problem and acute rural depopulation. In 1974, two experimental areas each of 8 ha (20 acres) were set up in the valley of the Golo in a sheep-rearing area of North Central Corsica. Different plots were established to study methods of pasture improvement through burning, crushing and fertilising. It was been found that crushing of the "maquis" brush, followed by a annual application of 100 kg each of N, P and K favours naturally occuring grasses, forbs and legumes providing excellent pasture for the Corsican milk ewes, and, if carefully managed, effective fuel breaks in the dense inflammable "maquis" brush (Etienne 1975). The cost of such pasture improvement is quite reasonable, at about 3,000 Francs/ha including fencing (approximately $242/acre).

As a complement to these experiments, the Interministerial Mission has used aerial photographs and field studies to make a complete inventory of Corsican soil potential, natural vegetation and fire frequency. This gives a cartigraphy of potential land-use, indicating the zones most susceptible to fires in terms of frequency and ecological significance ; those areas suitable for grazed fuel-breaks, cultivated fuel-breaks, reafforestation etc. In this way, it is hoped to break up are large expanses of brush, improve pasture for domestic livestock and game animals, reconstitute some real Mediterranean-type forest and protect rural villages from fire.

c) Restoration of the social and ecological role of Mediterranean natural areas.

At present, there are considered as "underdeveloped" and of no value whatsoever except for potential housing development. The regional and departmental administrations must decide what management could be possible for each natural area so that it is recognized as having a definite economic and/or ecological function in the overall land-use pattern.

To test out the possibilities of land management for fire protection and control, several Pilot Areas were created in accordance with the forest protection law of 12th July 1966.

There are now 7 Pilot Areas in the Mediterranean Region covering a total of 192 500 ha (475 300 acres) of which about 75 % is brush and forest (Blais, pers. comm.). They are now considered as demonstration areas of fuel mangement techniques. The majority of these Pilot Areas, that is 90 % or more, are private property. The State has financed the construction of primary and secondary fuel and fire breaks linking natural fires barriers such as ridges, vineyards, fields etc. These Pilot Areas have also been equipped with forest pathways assuring easy access and security for firemen, water points of various capacity, tarmacked heliports for fire-fighting and picnic areas for tourists.

Although these Pilot Areas have satisfactory fire statistics, it is evident that many of the fire and fuel breaks are unaesthetic and quite useless against forest fires backed by strong föhn winds (Mistral). Maintenance is also a problem as private landowners do not or cannot finance the necessary work, and state funds are lacking.

In the future, it is hoped that wider, functional fuel breaks will be created according to soil potential for pasture, reafforestation, vineyards, etc.

An inventory of the type undertaken by the Interministerial Mission in Corsica will help enormously in deciding what land-use is possible not only for the Pilot Areas but also for the rest of the Mediterranean region.

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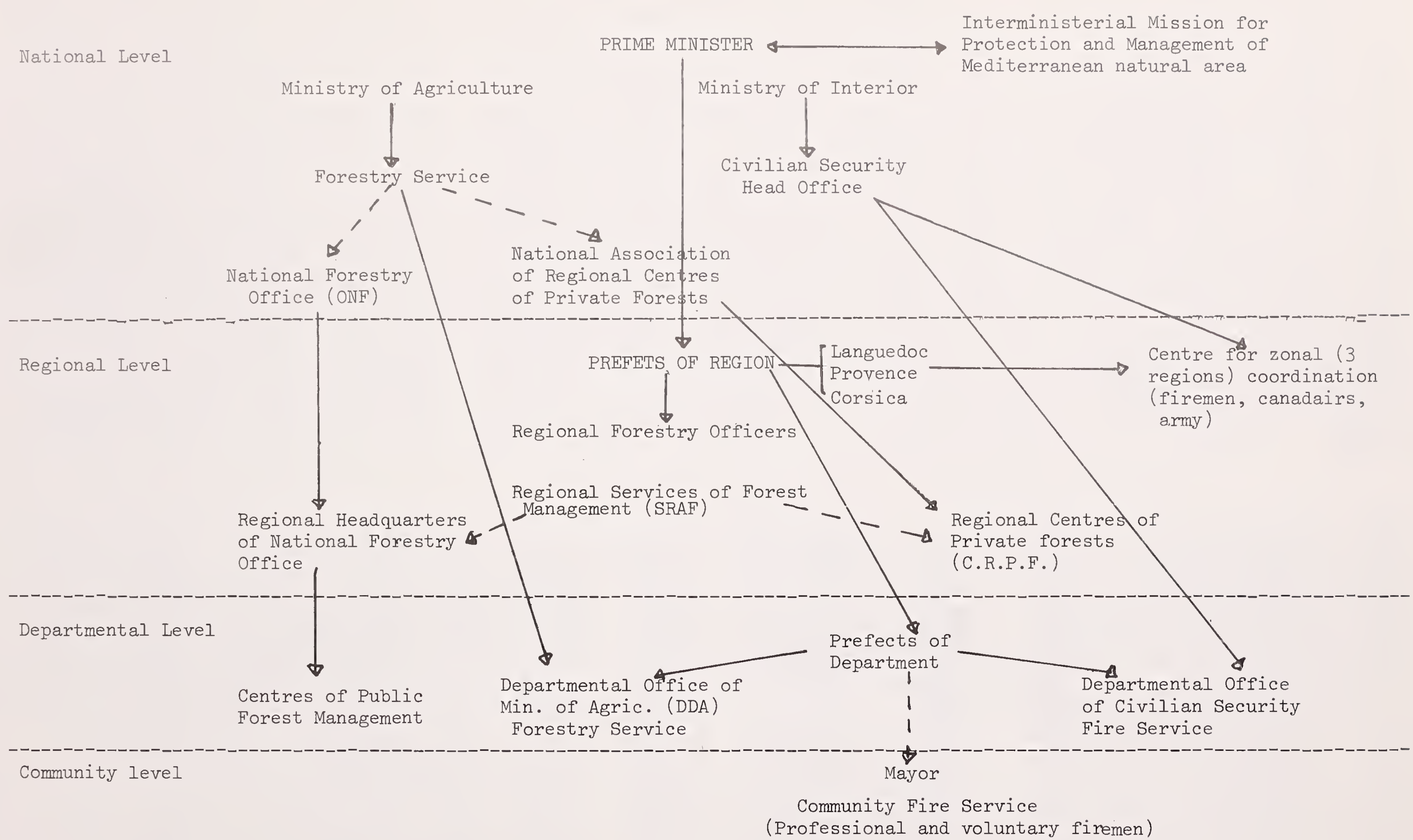
APPENDIX : ADMINISTRATION OF FOREST FIRE CONTROL AND FOREST MANAGEMENT IN THE FRENCH MEDITERRANEAN REGION.



——→ Hierarchal administrative connections

– – → Authoritative connections

FIRE AND FUEL MANAGEMENT IN PINE FOREST

AND EVERGREEN BRUSHLAND ECOSYSTEMS OF GREECE [1/]

Leonidas G. Liacos [2/]

Abstract: Wild fires are frequent and very distractive in Greece's forests. The ecological role of fire seems to be very important in the warm zone pine forests and in the evergreen brushlands. Fuel accumulation on forest floor creates many problems in their management. Fuel control burning in combination with intensive thinnings seems to increase the value of timber produced in quantity and in quality, to provide a significant forage production, to improve conditions of natural regeneration, and to reduce greatly wild fire hazard. Evergreen sclerophyllus brushlands are, also, very succeptible to wild fire. Their conversion by control burning to grasslands shows that grazing animal production is significantly increased, and wild fire hazard minimized.

INTRODUCTION

Wild fires destroy every year a considerable part of Greece's forests. For the 12 year period from 1964 to 1975 the average per year burnt forest- and brush-land area was estimated at 9,200 ha, with an average of 558 fires per year and an estimated damage of about 1,500,000 U.S. dollars (Kailides et al 1975). The conifer forests of the low elevation warm zone, constituted, mainly, of Pinus halepensis Mill. and Pinus brutia Ten., and the evergreen schlerophyllus brushlands are the most susceptible to wildfires, of which there are burnt annually and in average 0.525% and 1.041% of their total area, respectively.

Therefore, the elimination or at least the reduction of fire hazard of forest-lands of Greece is of paramount importance. The up to now policy, followed by the responsible authorities (Greek Forest Service) centers on the well known all over the world technique of fighting with all means against started wild forest fires. Also, a great effort is made to prevent forest fires by people's education and by a close supervision of forest lands during the summer time and especialy during the periods of high fire hazard.

The fuel management technique, that seems very promissing, and that will be the subject of this report, is still far from being considered by the responsible officials as an effective means for forest fire prevension. It remains,yet, within the area of research with some demonstrative attempts, that, however, give good promisse for the future.

THE WARM ZONE CONIFER FORESTS

Conifer forests of the low elevation warm zone of Greece occupy a large area, representing the 24.7% of its total forest area.

The significance of these forests is high, for they have a very great environmental, mainly, value (landscaping, recreation, buffering zone against ever increasing pollution etc.) neighboring the main urban and industrial centers of the country, and covering the long sea coast zone.

Wild fire hazard in these forests is high. The dry, generaly, climatic conditions character-

[1/] Presented at the Symposium on Environmental Consequences of Fire and Fuel Management in Mediterranean Ecosystems, Palo Alto, Calif. Aug. 1-5, 1977.

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izing that zone, and the conservative management practices applied there, favor the accumulation on the forest floor of havy very inflammable fuel, that can start burning any moment during the long dry summer season. Their location near urban centers and along the long sea coasts with heavy tourist traffic, magnify the risk of starting fire.

Control burning techniques, wisely used and properly applied, will, undoubtly, have beneficial effects, as the relative research work, developed in the past 10 years, has indicated.

Ecological Aspects

One of the climatic features of the warm conifer zone, along with high temperatures, is the shortage of soil moisture for a long part of summer period. It is rather true, although the relative research work is very limited, that early or late July there is no or insignificant only available water in the soil (Kotoulas 1965). It is well known, that in the eumediterranean zone the water is the main limiting factor of plant growth. This limiting effect of lack of water is much emphasized, when management practices keep the stands heavily stocked, with the result of a severe competition developed among the densily growing trees. Aerial part of trees are, thus, low in moisture, during the hot summer period, and, therefore, very inflammable.

The warm zone conifers are light tolerant species, and under the bright Mediterranean weather the understory vegetation grows densily, that, besides, aggravates the competition conditions for water in the ecosystem, and consequently magnifies wild fire hazard.

Under these dry conditions the litter crop and the number of dry branches of the trees become high. Natural prunning does not take place, given, in addition, the high oleoresin content of the pine species in question, and litter decomposition is very slow. Thus, a considerable quantity of very inflammable fuel is stocked, arranged in a perfect way to carry-on the fire to the canopy of the stand (fig. 1).

This accumulation of dead plant material, almost not at all decomposed, leads, evidently, to an interruption in the cycle of the cycling pool of nutrients, that not only affects negatively the productivity of the ecosystem, but it also creates disturbances in the function of the system.

Undoubtly, fire that may easily light under these conditions even naturally (Liacos L. 1974) reestablishes the interrupted cycle of cycling pool of nutrients and thus contributes to the conservation of the productivity of the system. Obviously, in this process fire plays an important functional role in the ecosystem, that allows to say that fire constitutes an important ecological factor of the eumediterranean pine forest ecosystem.

Figure 1- Pinus brutia stand in island Thassos of about 80 years old with a dense brush understory vegetation of more than 2 m high (see a forest guard standing-up on the left).

An other factor of the eumediterranean pine forest ecosystems, that partially contributes to the regular cycling of nutrients, are the herbivore animals, that under economic utilization of the said ecosystems are the grazing livestock or wildlife animals. Therefore, it could be said that grazing animals, also, are an important factor of the ecosystems in question.

In conclusion, we might say that fire and grazing-browsing must be considered with ecological understanding in the eumediterranean conifer forest ecosystems, and we must make them most profitable for the system by their proper treatment to increase net productivity, instead of fighting against them.

Management Aspects

The treatment technique used up to now in the management of the aleppo and brutia pine forests is mainly characterized by the conservative principles of middle-european classical sylviculture. The primary task of sylvicultural treatment from the young stage

to the stage of preparation for natural regeneration of the stand a few years before the end of the rotation time is to keep the stand close enough, in order to eliminate or to limite as much as possible the growth of competitive understory vegetation, and to obtain the natural prunning of the trees.

In fact this can not be achieved, because of the specific ecological properties of these very valuable pine species and the ecological feature of their climatic area (fig.1 and 2).

Figure 2- Pinus brutia stand of about 30 years old with dead branches remaining on tree trunes.

Moreover, this technique decreases greatly the net production of commercial timber in quantity and in quality, as well as the resistance of the stands against wild fires and the various pests. (fig. 3). In an ecosystem with a strict limiting factor as the water deficiency is for the greatest part of the vegetative period, it is at least unwise to invest energy in plant tissues that not only have no value for man kind, but further constitute the feeding source for severe enemies of the forests (fires, pests). This problem remains almost the same from ecological stand point even in intensively treated stands with cleanning operations, with the difference that in this case the cost of production is higher, and therefore net income is lower. Even with cleanning cuts and in

Figure 3- Pinus halepensis thick stand of about 25 years old with dead and dying trees because of strict competition.

following with regular thinnings under the conservative sylvicultural treatment mentioned above, there still exist a competition or, more exactly a density effect among trees of the stand, with the result of portioning the potential wood production in a big number of individuals, that leads to a lengthening of rotation time.

An other undesirable consequence of the traditional management of the forest in question is that natural regeneration conditions at the end of the rotation time are not favorable. A dense and very competitive understory brush, mainly, vegetation and an undecomposed litter layer of about 3 cm thick (Kotoulas 1965, Liacos 1973) do not allow the establishment of seedlings.

Control Burning in Fuel Management

The use of fire under prescription in the forests of aleppo and brutia pine, fed upon the accumulated on the floor fuel, seems to meet the ecological functional requirements of the system, and might be of great value and of considerable economic advantage for the management of these forests.

According to the brief analysis that was given above, it was thought that if with the help of control burning of the fuel it could be possible to substitute the brush understory vegetation by a cover of range plants under an open canopy of properly thinned stands, the fire hazard could be almost eliminated, the mana-

gement of the forest could be more effective for increased timber production in quantity and in quality, the wise use of the forage produced by grazing of livestock or/and wildlife animals would give a significant additional income every year, and environmental pollution from wild fire would be minimized.

More specificaly, with the control burning of the fuel, and under a proper grazing use of the forage vegetation conserved as an understory vegetation, it could be possible to have the following main advantages:

Application of Intensive Management of Forests

Free from the worry of establishment of an undesirable understory vegetation, the density of the stands from the young stage up to the rotation time could be kept in the proper degree, that would make full use of existing and improved each time growth conditions, functioning the longest possible time during the period of vegetative activity, and that would invest the net primary production of the system on commerciable most valuable products (wood, oleoresin) in the shortest time.

The specific benefits of such a treatment of the stands are as follows:

Lower Stocking: With a relatively small number of trees kept busy in the forest operation, functioning for longer time than in a thick stand (governing factor the available soil moisture), the working (stocked) woody capital is comperatively low and therefore its employment most profitable.

Better Quality of Timber Produced: Assembling the same net production on a smaller number of trees, the timber produced will be of larger dimensions, and therefore of higher value.

Higher Quantity of Timber Produced: Eliminating the competition of the understory vegetation in respect of soil moisture, that is the limiting factor of the ecosystem, it is expected a larger quantity of wood production.

Shorter Rotation Time: The trees in a thin forest stand will reach the diametre of technical maturity in a smaller number of years, that makes possible to have the economic advantage of a shorter rotation time. The shortening of the rotation time of a forest stand, that, especially, suffers from high fire hazard, is of extremely big economic value in forest business.

Justification of Fertilization: Since the forest tree floor, as well as the understory vegetation is constituted of desirable plants in the proper density, any fertilization would have beneficial effects at the highest degree upon the expected production and therefore it would be economically justified in the highest degree.

Successful Regeneration: The control of brush understory vegetation by prescribed burning and the relative supression of herbaceous cover by grazing, create and maintain very favorable conditions for the establishment of seedlings (especially survival), that make certain a successful regeneration of the stand.

Insect Control: It is propable that fuel burning might control some of the very destructive insects.

Production of Secondary Annual Income

No doubt, in forest operations, working with long waiting times, the possibility of creating sources for annual income is always desirable. The application of control burning technique could, exactly, create such opportunities:

Production of Valuable Animal Products: The growth of desirable forage plants under the open canopy of the stand give the possibility of a secondary annual income, that improves economic condition in forest operations.

Betterment of Recreation Conditions: The production of valuable forage improves greatly the conditions for the prosperity of game animals, that further increases aesthetic value and the recreation use of the forest.

However, all these main advantages,would be of real value under the conditions that the application of fire would not cause any damage or functional problems into the system.

Thus, before going-on with the application of control burning in large scale, it was necessary to find out:

1. Whether aleppo and brutia pine trees could stand the heat released during the control burning of fuel.

2. Whether burning of the fuel under control conditions is effective in killing understory plants of the maquis vegetation, of which about all sprout vigorously after fire.

3. Whether humus and mineral soil are affected by the heat released.

4. Whether soil erosion problems raise after burning the litter on the forest floor in connection with the effect of fire upon soil infiltration conditions.

5. Whether the establishment of an herbaceous plant cover in substitution of brush understory vegetation would be possible, and what technique would be the most effective.

Research Carried-on: First Results

For testing the above mentioned advantages of control fuel burning, and for answering the questions born from its application, a set of experimental plots was established, beginning the year 1967, in an artificially created stand of brutia pine of 30 years old and with an average density of 1100 trees per hectare, and in an aged natural stand of the same pine species of more than 80 years old. Besides, an experiment was designed in newly created stands by planting 6 month old seedlings under three different spacement (2X2 m , 3X3 m and 4X4 m) with and no fuel control burning that was established 5 years ago.

With these experimental set: (1) in a stand that passed its rotation time and of which natural regeneration was impossible for the reasons explained above (fig. 1) (2) in a middle age artificial stand with evident the density effect (severe competition for water) among trees and the stored undecomposed litter and dead branches (fig. 2) and (3) in an artificially created stand in which the control burning in connection with grazing of understory herbaceous vegetation would be tested in different stand densities under conservative and proposed intensive management (fig. 4)[1]

The up to now results are encouraging. It seems that the hypothesis made for the advantages of intensive management, thanks to the possible application of fuel control burning, is rather justified. For it has been rather proved by the experiment that:

Resistance to Heat: Brutia pine and for one more reason aleppo pine endure control burning very well (fig. 5).

[1] Details of the experiment design, could not be given here, because of the limited lenght of the present report.

Figure 4- A general view of establishment by plantation experimental plots to test the propable advantages of fuel control burning.

Figure 5- Pinus brutia stand where fuel burning was practiced for three times within 9 years following three consecutive thinnings.

Fuel Control: Understory brush vegetation can be killed after repeated burning for several times. Measurements of fuel weight made after the third control burning (in a rotation of 2 or 3 years) have shown that brush weight on forest floor under control and no burning was 3.6 ton/ha and 14.1 ton/ha, respectively. The most important result, however, is that on the plots where control burning was applied the remaining on the floor fuel was composed of relatively large diametre least inflammable woods, that have, in contrary, a higher in respect to volume weight (fig. 6).

Figure 6- Pinus brutia stand immediately after fuel burning with only large diametre wood remaining unburnt.

Humus Status: Humus was not at all affected by the heat released during the fuel burning, that consumed almost entirely the niddle litter. Thermometers, placed upon the surface of mineral soil and within the very thin humus layer, have shown maximum temperature of 15°C, while air maximum temperature was 16°C....

Soil Erosion: Soil erosion was not noted. Infiltration conditions were not tested to see wether hydrophovous substances were produced or not as Dr. DeBano found-out in similar cases in California (Debano 1973). However no signs of exessive surface water runoff were found.

Grass Cover: The establishment of herbaceous vegetation in substitution of the brush cover seems to be possible, although the first results are not very satisfying (fig.7). There is a need for more research, that should refer not only to the choise of plant species and the establishment technique, but also to the soil conditions after burning.

Stocking of Stand: The plots under fuel control burning were gradually brought after four consecutive thinnings to 115 m^3/ha with a density of 280 trees per hectare in the age of 37 years, and a median b.h.d. of 29.3 cm. The similar plots under conservative sylvicultural treatment have 273 m^3, 700 trees and 27 cm, respectively. The increament of the stands by surface unit was 8.5% and 3.85% respectively. These clearly show that the employment of the woody capital is much more profitable when stands are treated intensively and with the use of fuel control burning (fig. 5) than according to classical sylvicultural methods (fig. 3).

Figure 7- Pinus brutia stand under intensive thinning and fuel control burning with grass vegetation covering gradually the soil.

Rotation time: Trunk analysis at the beginning of the experiment, when the stand was of 30 years old (the stand was absolutely even aged since it was artificially created) shows that the competition started about 15 years before. (fig. 8). For the first 15 years of their growth they reached a diameter of 12.33 cm with an average annual ring width of 4.11 mm. During the second 15 year period, when competition among trees was gradually increasing, the diameter added was 21.93 cm with an average annual ring width of 3.20 mm. This dif-

Figure 8- A trunk disk of a tree had grown under competition in a dense stand of 30 years old. The density effect is evident after the first 15 years of its age with narrow annual rings.

ference in increament of tree diametre was evidently due to competition, as it was verified by the increase of diametre increament after the consecutive thinnings, done in the plots under intensive control burning. However, their reaction to thinning, after been for about 15 years under severe density effect, should not be expected to be immediate.

This facts strengthen the hypothesis that, if thinnings were applied according to the needs of the stand without worry about the competition of the understory vegetation that would grow more luxuriously after opening the forest canopy, the increament of the trees diametre could be conserved at the same, more or less, rate. This would allow to reach the b.h.d. of 45 cm, that generaly constitutes the main critirion for fixing the rotation time, in the age of 30 to 35 years of the stand. The Rotation Time in brutia pine forest management is reached now at an age of 60 to 70 years.

Timber Production: Although the 9 year data available up to now, obtained especially from stands that up to 30 years of their age did not, actualy, received any treatment, and grew since their artificial establishment in a relatively dense state, are not sufficient, they indicate, rather clearly, that if brutia stands were treated with intensive thinnings and control burning of understory vegetation the timber production would never be lower than in heavily stocked and not intensively thinned stands (fig. 9).

As to the quality of timber produced it is evident that, when the wood produced is stocked in a smaller number of trees, their diametre, and consequently their value, is comparatively higher. Figure 10 gives the trend of b.h.d of pine trees in both treatment since the start of the experiment. Individual pine trees on the plots under control burning have, now, a more valuable timber.

Fire Hazard: Figures 6 and 7 speak clearly, indicating that fire hazard of pine stands is by far smaller after control burning of fuel on forest floor. After three consecutive burnings in 9 year period, the fuel on forest floor was reduced from 25 ton/ha to 4 ton/ha. In addition, the composition of the fuel has been greatly improved after control burning in respect to fire hazard. In the plots under burning the inflammability of the remaining coarse fuel is very-very low (fig. 6). No doubt, after a few more burnings all the remaining material of thick stems will be entirely consumed, and the minimization of fire hazard will be evidend.

Natural Regeneration Conditions: Data show

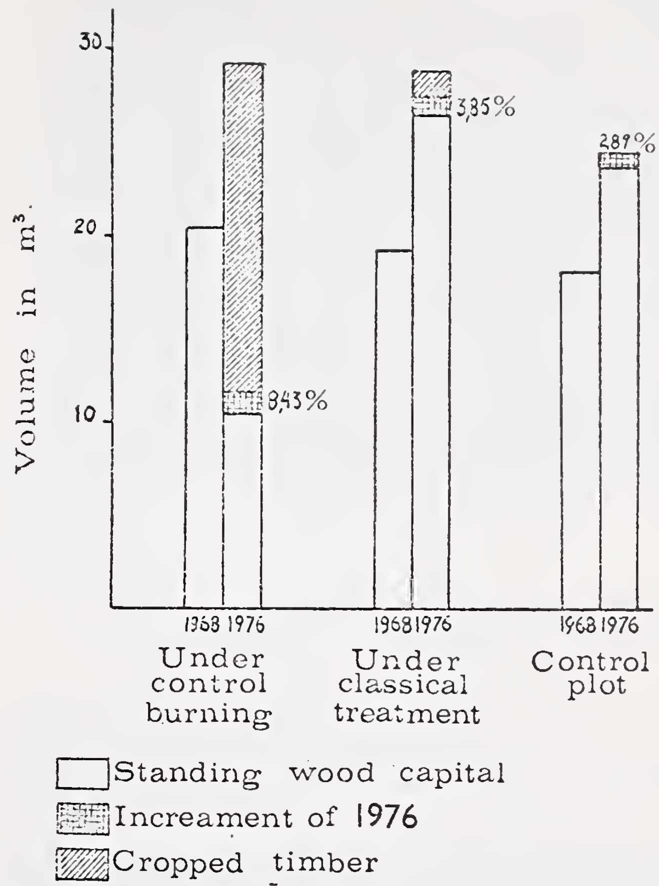

Figure 9- Trend of timber produced (standing and cut) from 1968 to 1976 on the plots under intensive thinnings and control burning, and under classical sylvicultural treatment.

that natural regeneration of the stands is much improved after fuel control burning. Seedlings of more than one year old, that is an indication of successful regeneration, were only found on the plots under control burning. There were found surviving 15/m^2, while they were absent on the plots under classical treatment. Seedlings of less than one year old amounted to 20/m^2 and 16/m^2 respectively.

Forage Production: It is quite early for evaluating the forage production, that will result from the intensive and with the practice of control burning technique. However, the limited up todate data show that during the young age of the stands, managed under the proper tree density[1/], the forage produced amounted

[1/] As proper tree density of pine stands from regeneration time is considered the one that eliminates any competition among trees of the stand and that can give useful products, covering at least the cost of production, at the first thinning, considered necessary for raising started competition.

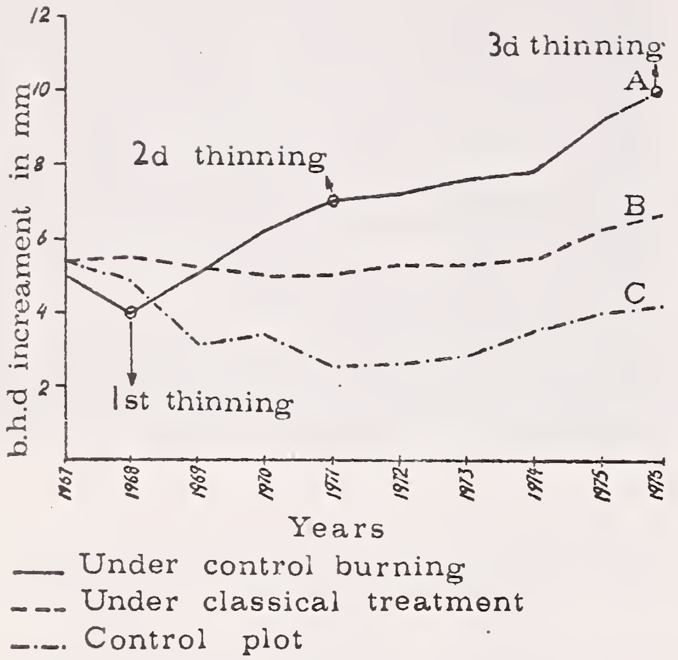

Figure 10- Trend of mean b.h.d of trees on the plot under conservative sylvicultural treatment and under control burning.

to 900 kg/ha.

THE EVERGREEN BRUSHLANDS

Maquis formation (chaparral) and sclerophyllous evergreen brushlands, in general, occupy a large portion of Greece's territory.Their surface is estimated to 783,000 ha, that represents about 30% of the country's forestlands.

The economic value of these brushlands was in the past quite important, for they provided the fuelwood to a considerable part of country's population. At present, the wood of brushland species has no value. In contrary, their value is very high for landscape management and for watershed protection.

Browse production in evergreen sclerophyllous brushlands is quite important. However, several of their plant species are not or little palatable, and their nutritive value comperatively low. L. Liacos and Ch. Moulopoulos (1967) report that annual browse production (foliage) and tender part of shoots) of brushlands been in excellent condition and constituted almost entirely by Quercus coccifera L., one of the most productive and valuable browse species, amounted to about 750 kg/ha.

Fire hazard of evergreen brushlands is very high during the summer time. Competition among individual plants for soil moisture begins very early. Liacos and Moulopoulos (1967) report that moisture content of browse falls to 48% by late June and gradualy to 44% by early September. It is evident that their imflamability is, then, very high. Data for the last 10 years show that in average 4,450 ha of evergreen brushlands are burnt annually (Kailidis et al 1975). Wild fires of evergreen brushlands are quite hot, for they offer a large quantity of high energy content fuel, constituting a great danger for neighboring urban and industrial centers.

The conversion of brushlands to grasslands seems to be interesting. Single tests, made in the past, have shown that forage production after conversion of maquis to grasslands, made with a costly mechanical control of brush cover, was by far higher (five times more) than the corresponding browse production. In addition, fire hazard in grasslands, when properly grazed, and consequently fire danger for neighboring areas is, obviously, insignificant.

Control Burning for Brushland Conversion

A properly designed experiment was established in 1971, and carried-on since then, to test the effectiveness and appropriateness of control burning in converting brushlands to grasslands. And also, to evaluate the precise economique advantages of such a conversion, by comparing animal production of browsing animals in improved brushland plots, and of grazing animals in converted grassland plots. (fig. 11).

Figure 11- A general view of experimental plots of improved brush vegetation and of converted to grass vegetation with browsing and grazing animals freely circulating in the respective plots.

The up to now results can be summarized as follows:

Effectiveness of Control Burning Technique.

Although the experiment carried-on refers to a specific region with particular physiographic and climatic features, not representing the whole evergreen sclerophyllous brushland area of the country, we might say that control burning should be considered as a very effective and appropriate means in converting brushlands to grasslands.

Consumption of Brush Cover: The use of control burning some time in late September, when moisture content of brush plant tissues is low, creates a hot fire that kills the brush plants in a considerable degree (fig. 12).

Figure 12- A view of brush-plot after control burning in early spring, 1975

Confinement of Fire: Although burning was done at a time when fire hazard is very high, and the surface of burnt plots were only of 0.3 of an hectare, the fire was strictly confined within the periphery of the plots, without creating any danger of spreading the fire to adjacent brush area (fig. 11).

Establishment of Herbaceous Cover: A day following control burning of brush cover, a seeding of a mixture of valuable range forage species[1/] was done upon the hash. Although the first good rain after burning came more than a month later, the germination and the survival of seedlings was very satisfactory. (fig. 13).

[1/] There were seeded:Dactylis glomerata, Bromus inermis, Lolium multiflorum (as good competitor) Phalaris tuberosa and Lotus corniculatus.

Figure 13- A viw of burnt and seeded plot in the following spring. A quite dense herbaceous vegetation replaced the thick brush cover.

Brush Sprouts: Sprouting of burnt brush plants started in spring quite vigorous (fig. 12). Biological control (goat browsing) proved to be effective (fig. 14).

Figure 14- View of converted plot after biological control of brush sprouts by goat browsing.

Soil Erosion Control: Soil was not at all affected by surface run-off of rain water. Although the experimental area is very steep (inclination of about 75%) and the litter was completely consumed by the hot fire, there was not noted any soil erosion trace in a flow of about 100 m, that is the length of the experimental plot.

Forage and Browse Production: The two year

mean production of forage in the converted plots, and of browse in the improved brush plots, amounted to 11,500 kg/ha and 2,710 kg/ha, respectively. Three years after burning and forage plant seeding the composition of forage plant cover in the converted plots is as follows:

- Dactylis glomerata 11.5%
- Lotus corniculatus 1.2%
- Lolium multiflorum 0.3%
- Brush sprouts 10%
- Others 77%

Animal Production: The two year mean increase of life weight of grazing and browsing animals, used in the experiment under proper utilization of forage and browse produced, was 120 kg/ha and 70 kg/ha, respectively. It must be noted, however, that utilization in the converted plots was very conservative. The grazing period was there limited to two months, to encourage the good establishment of seeded forage plants.

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THE ROLE OF FIRE IN THE MEDITERRANEAN LANDSCAPE OF ISRAEL[1/]

Zeev Naveh[2/]

Abstract: Natural and man-made fires have played a decisive role in the evolution of Mediterranean landscapes in Israel and elsewhere. In vascular plants this is manifested by positive and negative feedback responses enabling direct fire tolerance or its avoidance by vegetative and reproductive regeneration and is closely interwoven with adaptive responses to other environmental stresses, especially drought and grazing. If not combined with destructive grazing, it could play an important role in the conservation of biological diversity and stability of present semi-natural landscapes. Its controlled use and/or prevention should, therefore, become an integral part of dynamic, multi-purpose landscape planning and management.

Key words: Fire ecology; Mediterranean uplands; Landscape evolution and management.

INTRODUCTION

Due to the destructive combination of fire and overgrazing in recent times, the important role of fire in Mediterranean landscapes has been overlooked and it has been mentioned only as a destructive factor, leading away from the "maqui-climax" (Zohary 1962).

However, the eminent ecologist, Walter (1968) recognized fire as one of the major ecological factors which shaped the Mediterranean landscapes and affected its present mosaic-like pattern of regeneration and degradation.

Naveh (1967) drew attention to the striking similarity in fire response of individual plants and communities of Mediterranean shrub ecosystems in California and Israel, as manifested by rapid regeneration of the same individual and/or by a shift in generation through volunteering seeds of burned mother plants. Such a process of "auto-succession" (Hanes 1971) is obscured, in general, by a short interlude of herbaceous plant domination. He also pointed to the comparable role of fire in both Mediterranean environments in the evolution of shrub ecosystems and in their maintenance in a rejuvinated and vigorous state, coupled with the mobilization of tied-up nutrients and the removal of heat-unstable phytotoxic, allelopathic agents.

The object of this paper is to summarize our present knowledge of the impact of fire on natural and semi-natural landscapes of Israel in past and present and its practical implications for land-use planning and management.

THE NATURAL FIRE ENVIRONMENT OF ISRAEL

Israel is located on the eastern shores of the Mediterranean Sea and on the equatorward border of the Mediterranean Climatic Zone and the south west corner of Asia. It is distinguished by a great bioclimatic, physiographic and phytogeographic diversity. It ranges from extremely arid and arid desert and steppe zones in the South and Lower Jordan Valley, with 100 mm and less mean annual winter rainfall to subhumid and humid Mediterranean regions up to 1000 mm annual rainfall. These include the mountainous belt in the upper Galilee, rising to more than 1000 meter, with

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[1/] Presented at the Symposium on Environmental Consequences of Fire and Fuel Management in Mediterranean Ecosystems, Palo Alto, Calif. Aug. 1-5, 1977.

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various Cretaceous and Eocene soft and hard limestones and basaltic plateaux. Natural vegetation and wildland ecosystems have been retained here on about two thirds of the area, on soils too rocky and/or shallow and steep for cultivation. From these non-arable upland wildlands about 50,000 hectares have been planted chiefly with highly inflammable pine forests of Aleppo pines - *Pinus halepensis* - about 50,000 are gazetted as nature parks and reserves, about 30,000 are considered low value natural scrub forests and the remaining 150,000 hectares are actual and potential grazing lands. The natural vegetation canopy of these wildlands consists of various woody and herbaceous degradation and regeneration stages of Mediterranean sclerophyllous forests and woodlands. On their xeric ecotones to the southern and the eastern slopes of the mountains, they are bordered by Irano-Turanic grassy Steppe vegetation of the semi-arid transitional zone.

If not grazed too heavily, the native woody and herbaceous vegetation of these upland ecosystems, in contrast to those of the drier zones, is dense enough to carry through fire in the dry season when meteorological conditions are suitable.

Israel has a typical Mediterranean "fire bioclimate" (Naveh 1973a,b) with a long, hot and dry summer from May to October with maximum average daily temperatures around 30°C, average relative air humidities of 50-60% and frequent heat waves of "sharav" at the beginning and end of the dry season, when temperatures rise above 40°C and relative humidities can drop below 30%.

FIRE HISTORY OF MEDITERRANEAN LANDSCAPES IN ISRAEL

At present, lightning plays only a minor role in naturally caused wildfires in the Mediterranean region, in contrast to California. But there is no reason to suppose that natural fires, caused by lightning as well as by volcanic eruptions have not raged since the Late Pliocene and Early Pleistocene and especially since the desiccation of the last Interglacial Wurm period, when the present climatical fluctuations between wet and dry seasons and the Mediterranean flora and fauna became finally established (Butzer 1972). Such a single lightning fire on a dry day, if not put out immediately, could catch the undisturbed, dense and highly inflammable woody and herbaceous vegetation and spread rapidly over vast areas. Such fires on wildland pastures were already mentioned in the Bible in connection with "the heat of the summer drought" by the prophet Joel (1/11).

Fire may, therefore, have acted as a dominant environmental agent together with drought in the evolution of the Mediterranean flora in a similar way as that recognized by Axelrod (1958) for the evolution of the Madro-tertiary geoflora of California.

The earliest conclusive evidence of the use of fire by paleolithic man has been furnished from the Mediterranean Region, at the Escale limestone cave, in the Durance Valley near Marseille. Here, in 1960, old bones, traces of charcoal and ash, fire-cracked stones and reddened hearth areas, estimated as more than 500,000 years old, were discovered (Pfeiffer 1969). More recently, Poulianos (1976) claimed the discovery of a cave, about 300,000 years old with similar evidence of use of fire in Northern Greece. This site, a karstic cave in hard limestone and dolomite, surrounded by *Quercus coccifera maqui*, has striking resemblance to the site of the Tabun Mt. Carmel caves in Israel. Here, wooden ash and hearths were found in the final Acheullian and Levalloisi-Movsterian levels of the Mesolithic period by Garrod and Bate (1973). According to recent findings in these caves (A. Ronen, personal communication, 1976) the evidence of the use of fire by these mesolithic hunters and foodgatherers as well as of occurence of fire in their surroundings reaches back for at least 150,000 years. The rich faunal collections in the Carmel caves point to the existence of advanced and diversified hunter-gatherer economies of the Upper Pleistocene "Palestinian Neaderthal" man. He may have used fire to open the dense forest and brush thicket and thereby created ecotones and secondary successions, richer in edible shrubs, grasses, herbs and tuber plants for man and game and thereby also facilitated hunting and gathering.

With increasing human populations and advanced hunting and food collecting economies, the extent and intensity of burning probably increased steadily and became more and more linked with grazing by wild and semi-domesticated ungulates, such as fallow deer, gazelle, wild goat and cattle. The steady increase in Mediterranean garigue, steppe and rock dwelling rodents from this period onwards, (Tchernov 1968) are indications of the gradual enlargement of drier, more exposed and rockier habitats in the vicinity. They can be interpreted as the first, fire-induced stage of the anthropogenic biofunction which has led through various cycles of the degradation and aggredadation to the final stages of Mediterranean landscape desiccation (Naveh & Dan 1971).

Fire has played a no less active role in

further phases of this anthropogenic biofunction in pastoral and agricultural ecosystem modification and conversions, in forest-clearing for cultivation and apparently also in the domestication of cereal crops.

The transition zones between the semi-arid steppic Irano-Turanian and the sub-humid Mediterranean woodlands are amongst the first known centers of successful cereal and stock-breeding economies. These regions include the most fire-prone Mediterranean biomes (Naveh 1973a) and also abundant here are the progenitors of our cereals, the large grained wild barley - *Hordeum spontaneum* and the Emmer wheat - *Triticum dicoccoides* (Zohary 1969). These annual grasses are amongst the most prolific fire followers, and post-fire collection of seeds, could have been one of the first logical phases in their domestication. Their fire-scorched seed dispersal units with big parched kernels can easily be collected after a wildfire and according to Harlan (1967) these primitive glumed cereals needed to be parched before they could be threshed and winnowed. Harlan & Zohary (1966) suggested that actual domestication and farming may not have taken place where these cereals were most abundant and could be collected from natural stands, but in adjacent areas. These include the maqui belt, in which the semi-sedentary Natufian cultures using flint sickles and grinding stones are located. As mentioned above, from the Mt. Carmel caves we already have the first evidence of use of fire and its possible after-effects on expansion of drier and more exposed sites. One should not discount, therefore, the importance of fire as one of the enviromental and cultural triggers of cereal domestication in the fire-swept drier grasslands and in the fire-induced maqui-edges.

Thus, after natural fire has already operated for many thousands of years as a major force in the biological evolution of this region, it also became the first vehicle of the cultural evolution which, in turn, effected the further evolution of biota and shaped their landscapes for at least 150,000 years.

Throughout the following phases of intensive agricultural and pastoral land use and especially from the Bronze and Iron Age until the Hellenistic and Roman period, the wide occurence of fire in Israel is well documented in the Bible, the Talmud, and Hellenistic and Roman literature. Naveh (1973b) has sited 28 references of fire and vegetation from the Old Testament and Felix (1963) cited Talmudic sources, showing that burning of stubble fields and thistles was a common way for field clearing and preparation and for the use of ashes as fertilizers.

The intentional use of fire by herdsmen to open impenetrable brush-thicket and to provide better and lusher pasture has been mentioned by Virgil in Aneid (X:405-411). This practice has been used in Israel by the Arab shepherds probably for more than a thousand years, since the Muslem Conquest, which marked the beginning of the darkest phase in agricultural decline and landscape desiccation, caused by destructive land use pattern. Such "Brand-cultures" have been described by several explorers of Palestine and Syria in the last centuries. Amongst them Anderlind (1886) mentioned the burning in connection with the use of ash of the wooden plants to improve the pastures and to avoid damage to the udders of the cattle and goats by thorny shrubs.

The present situation of wildfires in Israel and their causes is very similar to that described by Susmel (1973). With increasing forest use for tourism and recreation and increasing encroachment of wildlands by agricultural activities and urbanization, there is a rapid increase in the extent of fires, especially in the highly inflammable, dense pine afforestation. Thus there were more than 724 wildfires recorded in 1973 and the Forestry Department has to spend about 10% of its annual budget on fire prevention.

On the other hand, the increasing pressure on upland pastures around Arabic villages, has led to such heavy overgrazing that very little fuel has been left for fires, even in the dry season.

It should, however, be kept in mind that in many locations where traditional pastoral use has been abandoned, and in nature reserves and parks in maquis and woodland which are protected from fire, the piling up of dry grass fuel, litter and debris and the brush encroachment will lead finally to hotter and more devastating wildland fires. Such fire exclusion policies may lead to similar undesirable situations, as already encountered in the California chaparral areas (Hanes 1971).

In contrast to California, where prescribed burning has become an important tool in brush range and forest management (Biswell 1967), the rational use of fire in Mediterranean wildlands is still in its infancy.

Large-scale trials and farm operations of maquis brush conversion in Israel have shown that controlled burning followed by reseeding of perennial grasses, rotational-deferred grazing and selective arboricidal control of undesirable woody resprouters can

lead to manyfold increase in pasture output of 1000-1500 Scandinavian Feed Units/ha/year (Naveh 1960). At the same time it could also lead to increase of water yields from the converted watershed and catchment areas.

EFFECTS OF FIRE ON MEDITERRANEAN ECOSYSTEMS

The effect of fire on soil and vegetation in Israel has been described in detail by Naveh (1960, 1973a, 1973b). He showed the almost complete absence of traces of run-off, soil splashing, movement and erosion, even on fire-denuded slopes of 30-40%, after heavy rains in the first winter after the brush burn. The compacted ash layer of the incinerated litter, debris and semi-decomposed Aoo and Ao profiles provided ideal conditions for the rapid development of natural spreading and reseeded perennial grasses and other herbaceous plants in the "white ash seedbeds", as described also after hot chaparral fires in California (Bently & Fenner 1958).

He also pointed out that the greatest damage to these ecosystems is caused not by the fire itself, but by the heavy uncontrolled grazing and browsing, following immediately upon these wildfires in Mediterranean brush and woodlands. A clear distinction should be made, therefore, between these different situations.

As has been shown above, this vegetation has been exposed to re-occuring fires for such a long period, that only species and biotypes with best fire adaptations through post-fire regeneration from underground or fire tolerant parts had chances to survive. These adaptations can be best comprehended in a cybernetic context as homoeostatic feedback control responses to changes in the plant-environment system, induced by the fire. In these, the information of the catastrophic fire event and its ecological after-effects is partly transformed or re-coded as useful for survival of the gene-pattern, but that part which threatens it, is blocked. According to the Law of Requisite Variety (Ross-Ashby 1956) those genotypes in which this useful transmutet information as positive or negative feedback was large enough to endure the fire or evade it, has best chances for survival (Naveh 1975).

Most sclerophyll trees and shrubs and climbers rely solely on positive feedback fire-responses of vegetative regeneration and are therefore obligatory root resprouters. But all chamaephytes and herbaceous perennials are facultative resprouters with dual vegetative but also fire-stimulated reproductive regeneration (Naveh 1960, 1973a).

The native pine species *Pinus halepensis*, as well as *P. Brutia* rely solely on post-fire seed germination and are therefore obligatory seed regenerators. Fire apparently provided the only opportunity for their natural regeneration under a dense maqui understory (Walter 1968, Naveh 1973a).

Fire regeneration behaviour is closely linked with hydro-and phenoecological behaviour: The sclerophyll obligatory root resprouters are drought enduring, summer active, but the facultative root resprouters are drought evaders with more restricted summer activity. In these, positive feedback of fire-stimulated regeneration is coupled with morphological and physiological plasticity and agressiveness in ecesis of newly-opened, fire-denuded but mineral rich habitats. Thus fire has favoured not only the tenaceous maqui-dominant but also the evolution of opportunistic and potentially fast-growing subordinate species-dwarfshrubs, hemicryptophytes, perennial grasses, geophytes and therophytes - that remain for years as supressed relics near tree and shrub edges, rock outcrops and shallow soil patches, until their next fire-induced upsurge.

As also stated by Mooney & Dunn (1970), post-fire grazing pressure has acted as an additional powerful selective agent, favoring those species and biotypes which very soon after their fire-regeneration develop hard, thorny or distasteful leaves and twigs, but also those with highest vegetative regeneration capacities. In this way plants like *Pistacia lentiscus, Quercus calliprinus* and many others could overcome both defoliation stresses. We may also assume that the useful re-coding of this information from fire and grazing has predisposed them for further defoliation catastrophies from cutting and coppicing.

In Tabor oak *(Quercus ithaburensis)* woodland, the thick fire resistant bark of this tree is an efficient negative feedback defence mechanism for post-fire survival because the fire temperatures of the dry grass understory are not as high as in dense woody stands. The annual plants of these woodlands and those of open, semi-arid Steppe grasslands, which are even more fire-prone, are most successful fire-followers. Here, naturally, all feedback responses are centered around reproductive behaviour. Thus, early and prolific seed production, seed shedding and distribution by efficient dispersal mechanisms and seed dormancy and polymorphis - especially in legumes - increased the chances for escapement of fire and environmental rigor. Of special value in this respect is *trypanocarpy* - the capacity of grass dissemulates and *Erodium* and some others

to "drill" themselves in the soil with the aid of hygroscopic awns, callous tips and other torsion mechanisms. These, as well as heat tolerance (Naveh 1973a) may explain the stimulative effects of late-summer burning on herbaceous plant species diversity and especially legume abundance in such a lightly grazed, grass-dominated Tabor oak woodland (Naveh et al 1977, unpubl.). This favorable legume response is very similar to that after the removal of the grass cover-and mulch by grazing.

Fire may therefore play a role in simulating the grazing effect, if the latter is abandoned - as is the case now over large areas of Mediterranean grassland-uplands.

Of even more far-reaching implications is the beneficial effect of fire on biological diversity of Mediterranean shrub ecosystems and - consequently - the detrimental effect of their prolonged protection from fire or other defoliation processes. Our recent studies on plant and animal species diversity (Naveh et al. 1976) lend additional proof to the fact that prolonged complete protection of maquis from human interference leads to canopy closure and dominance of arborescent "climax" species - chiefly *Quercus calliprinos*, suppressing subordinate "successional" species. Thus, on Mt. Carmel such a protected maqui thicket had only 25 species per 1000 m^2, as compared with more open disturbed and "degraded successional" maquis, which also had a herbaceous understory, a much more complex and diversified vertical structure with more than 100 vascular plant species and also much more reptile, rodent and bird species.

Of special importance from the recreational point of view is the striking increase of flowering geophytes - including orchides - on burned maquis and dwarfshrub "batha" communities (Naveh 1960, 1971). The striking plant species richness of recently burned batha also in the drier Judean Hills was confirmed by A. Danin (pers. comm. 1977).

DISCUSSION AND CONCLUSIONS

We shall be able to give a more conclusive answer to the role of fire in the maintenance of highest biological productivity, diversity as well as neg-entropy and stability in these Mediterranean shrub-ecosystems only with the help of further, integrated ecosystem studies, concerned with post-fire dynamics of nutrient cycling and energy flow.

But our present knowledge is already sufficient to contradict both classical and more modern versions of climax and succession theories, assuming that in undisturbed "maturing" ecosystems, there is a trend towards increase in community stratification, complexity stability and diversity (Odum 1969, Margalef 1968): In closed and undisturbed maquis, diversity and complexity are declining and their increase in biomass is chiefly through accumulation of highly combustible fuel, increasing their vulnerability to fire and thereby increasing also their entropy. For such a process the term "aging" would probably be much more appropriate than "maturing" and this process is apparently prevented by fire. Therefore any attempt at reconstruction of the true climax communities should take into account the fact that fire has been an integral part of their composition, structure, productivity, neg-entropy and nutrient circulation from their earliest stages of emergence.

In the drier regions, the restricted winter rainfall and long summer drought, coupled with great fire hazard, has probably favored the domination of short-seasoned, drought and fire avoiding therophytes and facultative resprouting hemicryptophytes, geophytes and chamaephytes. Higher rainfall and better soil-and -rock moisture regimes, less frequent but hotter fires have probably favoured the dominance of drought tolerant, sclerophyll obligatory resprouting phanerophytes but have also opened niches for above-mentioned drought evaders. Somewhere along this moisture and fire ecocline, the dwarfshrub-dominanted bathas can be found. It should also be assumed that prior to the effect of man, the grazing pressure of herbivores, without being destructive, was sufficiently severe to act as an additional selective force through adaptive feedback responses.

Thus we can reach the conclusion that fire has contributed not only to biological diversity of genotypes but also to that of Mediterranean ecosystems, their composition, structure and niche differentiation.

However from the Upper Pleistocene onwards and especially during the Holocene, man has induced so many retrogressive stages from the prestine climax and has distorted this evolutionary process so much, that its reconstruction has become very difficult. This has led to the confusion of some quasi-stable vegetation stages with climax communities, instead of regarding them as potential seminatural vegetation types prevailing under a specific combination of natural conditions and distinct regimes of human disturbance or protection.

One of the main conclusions from study of recent biofunctions in Israel (Naveh & Dan 1973) was, that during the long phase of

agricultural decay and population decline in the last centuries a new equilibrium was established on those non-cultivated uplands, which were neither overgrazed and heavily coppiced nor completely protected, but moderately grazed and occasionally burned and/or coppiced. This man-maintained equilibrium among tree, shrub, herb, grass and geophyte strata contributed much to the biological diversity and attractiveness of these semi-natural landscapes and is one of their main assets for recreation and tourism. It should be ensured, therefore by continuation or simulation of these optimal defoliation pressures-including fire-under which they evolved.

RESUMEE: FIRE AND FUEL MANAGEMENT AS PART OF INTEGRATED LANDSCAPE PLANNING AND MANAGEMENT.

From this discussion it is obvious that our fire-and man-modified upland ecosystems are actual units of the semi-natural landscape As such they should not be comprehended with any preconcieved climax and succession theories but with a holistic system approach, as the concrete, visual, spatial and functional units of the Total Human Ecosystem (Egler 1970). In this, natural semi-natural and agricultural "bioecosystems", maintained and regulated by solar energy and bio-physical information, should be integrated with man-made- and maintained rural and urban-industrial "techno-ecosystems" (Naveh 1977). Landscape ecologists can further this integration by finding a compromise between the needs for conservation and reconstitution of these open semi-natural landscape units and the socio-economical needs of the society.

For this purpose it is necessary to transfer their "non-economic" richnesses into workable parameters for the land-use planners and decision makers. This has been attempted by multi-purpose strategies (Naveh 1974) aimed at maximizing their bio-ecological functions as last refuges for organic variety and as "life-supporting" systems and buffering zones for protection of watersheds and environmental pollution control and reduction of fire hazards; their socio-ecological, aesthetic and psychohygienic function for wildland and forest-outdoor recreation and their economic function for livestock, forest and water production and tourism.

A flow-chart of these strategies is presented in figure 1. The presently misused, low valuable uplands (A) have been subdivided into 3 major subsystems according to density of woody cover and degree of misuse. By protection they can be converted into dense, unpenetrable and monotonous maqui reserves (B) or by planting of pines into dense, highly inflammable forests (C). The two new options are based on ecological management of the soil-plant-animal complex and vegetation manipulations, including controlled fire and controlled grazing (D) and also multi-purpose afforestation and revegetation for the creation of semi-natural, multi-layered park and woodlands with local and exotic trees and shrubs of high cover, fodder, and ornamental values (E). D systems - as well as C forests can also be converted into such E systems and both D and E are divided according to their major utilization either for recreation (D_1 and E_1), for maximum compatible multiple use (D_2, E_2 or for fodder production for livestock (D_3, E_3).

The multiple-use benefits have been indicated in each system by relative ratings from nil to 5 (very high) and maximum values are achieved in most intensively improved and managed D and E systems.
Amongst these benefits is also resistance to fire hazards. This is inversely related to the density and bulk of vegetation and its fuel properties and to man-caused fire risks, it is lowest in highly inflammable pine forests and maquis and highest in overgrazed and denuded A systems. But in E systems it could be raised - even if these will be used for recreation by replacement of xerophytic native plants by more mesic, succulent and lusher shrubs and trees, especially if used also for grazing, and by creating special fire protection zones in which vegetation is kept low through grazing, herbicides and low-inflammable plants. Certain promising species have been selected for this purpose and are tested now in northern Israel forests (Naveh & Ben Ezrah 1977).

For the assessment of compatibility of these different land used and their mutual influences a cybernetic sensitivity model (Vester 1976) was used (figure 2). Fire hazard resistance is highly effecting forestry and watershed protection and is highly affected by forestry, livestock and recreation.

In order to ensure the inclusion of wildfire and both its detrimental and desirable effects in the regional planning process, a model of fire analysis has been developed (Derman & Naveh 1977). It is based on the prediction of probabilities of fire occurence, its ignition and spreading and on the evaluation of its short- and long-term results, taking full account of all intricate positive and negative feedback relations. On base of the appraisal of desirable or detrimental effects of fire and its prevention on the realization of planned goals and targets, actual decisions in landuse-planning and management can be taken.

These models were also presented at the recent FAO/UNESCO meeting on forest fires in the Mediterranean Region (Naveh 1977b). In this meeting traditional, whole-sale fire-condemnation attitudes of foresters were balanced by unprejudiced views on the role of fire and its prevention. This was reflected in the final resolutions, recommending the consideration of controlled burning and grazing for forest fuel-management and especially multipurpose afforestation. It is hoped that this will be implemented by mediterranean foresters in the near future.

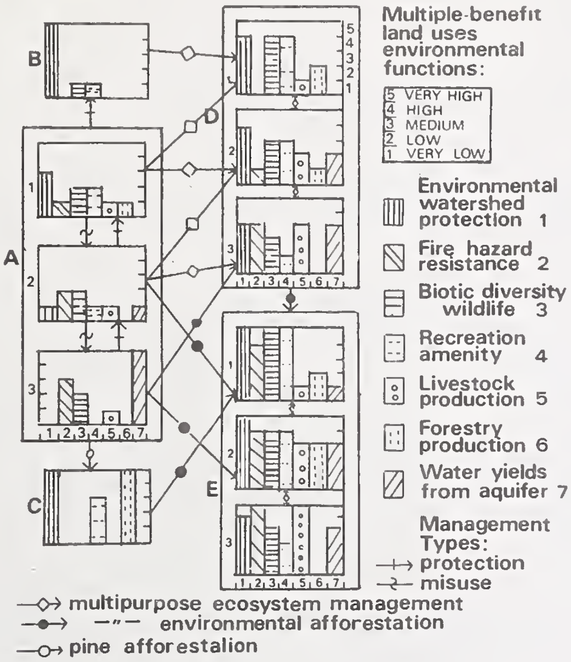

Figure 1--Management flow diagram of Mediterranean upland ecosystems.

Effect from ↓ on →		A	B	C	D	E	F	G	AS	Q
Environmental & watershed protection	A	●	0	0	3	1	0	3	7	0.8
Fire hazard resistance	B	1	●	1	1	1	3	3	10	1.1
Biotic diversity & wildlife	C	1	1	●	3	1	1	1	8	0.9
Recreation amenity	D	2	3	1	●	1	2	1	10	0.7
Livestock production	E	2	2	3	3	●	2	2	14	1.7
Forestry production	F	3	3	3	3	3	●	3	18	2.2
Water yields from aquifer	G	0	0	1	1	1	0	●	3	0.2
	PS	9	9	9	14	8	8	13		
	P	63	90	72	140	112	144	39		

AS · Active Sum
PS · Passive Sum
Q · Quotient AS:PS

0 · NO INFLUENCE
1 · SLIGHT INFLUENCE
2 · MEDIUM INFLUENCE
3 · STRONG INFLUENCE

ACTIVE ELEMENT
highest Q: F, (E)

PASSIVE ELEMENT
lowest Q: G, (D)

Figure 2--A cybernetic sensitivity model land-use factors.

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ECOLOGY OF SYSTEMS AND FIRE MANAGEMENT IN THE ITALIAN MEDITERRANEAN REGION[1/]

Lucio Susmel[2/]

Abstract: The ecologic conditions of the Italian Mediterranean systems are examined and some features of theirs are taken into consideration as fire determinants. Owing to the actual serious degradation of forests and maquis, the considerable increase in the number of fires in recent years worries all the more. The problem has been faced only recently (1975) with a new fire control law. Consequently fire control management can be planned to day on modern grounds and with technical means. In order to attain this purpose however, it is necessary to overcome several obstacles (cultural level, personnel, financing, etc.). Some administrative districts started some years ago and can now avail of a fire control service that proves fairly efficient, even if it is still incomplete.

Key words: vegetation; ecosystem; fire management.

Of about 30 million Ha forming the Italian national territory, 6 million Ha are covered by forests, 20% of which is found in the region to be considered in strict sense of Mediterranean climate (that is, a half of the surface of the country). Its vegetation is characterized by holly oak (high forest and coppice, 50 thousand Ha), by cork oak (100 thousand Ha), by Mediterranean pines (100 thousand Ha) and by maquis, garigue and grasslands (2 million Ha). The remaining forest area is found on hill and mountain sites, with different climates (fig. 1), while plains and low hills are exploited by agriculture. The following hints strictly refer to Mediterranean vegetation types (pinewoods excepted), some of the most prominent aspects, regarding ecology and the problem of fire, will be taken into consideration in this paper.

Although the outstanding characters of the Mediterranean climate are homogeneous (summer drought, moderately cool and rainy winters), owing to the extent in latitude of the Italian peninsula (∿ 12°), it shows a high variability in some parameters (rainfall depths, dry period length, average of temperatures and thermic extremes) that affects plant ecology and consequently ecosystem aspects. The limits of the climatic variability are illustrated in fig. 2.

[1/] Presented at the Symposium on Environmental Consequences of Fire and Fuel Management in Mediterranean Ecosystems, Palo Alto, Calif. Aug. 1-5, 1977.

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As far as the structure and the functionality of systems and fire danger are concerned, the limiting factor is summer water availabili-

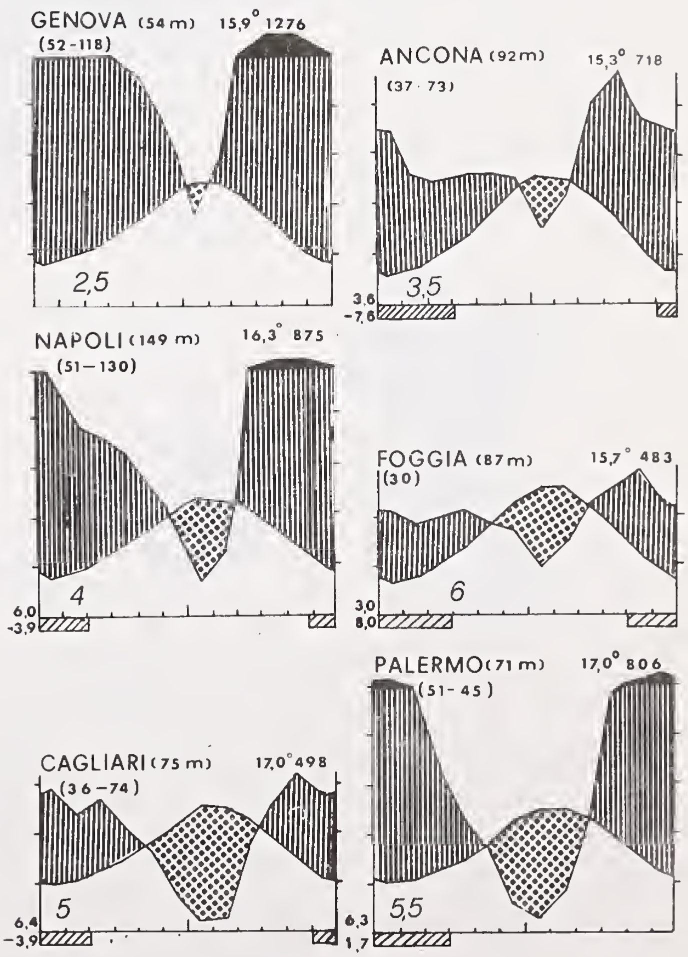

Figure 2--Climatic variability in selected cities of Italy. 4-6=n° dry months.

ty (or deficit) that can be evaluated as "dry period duration" and is estimated either with some formulas of the water balance or with direct measurements shown as follows (5):

site	number of dry months	potential water balance
Genoa	2.5	+430
Florence	3.5	- 44
Foggia	6	-379
Syracuse	6	-343
Cagliari	6	-351

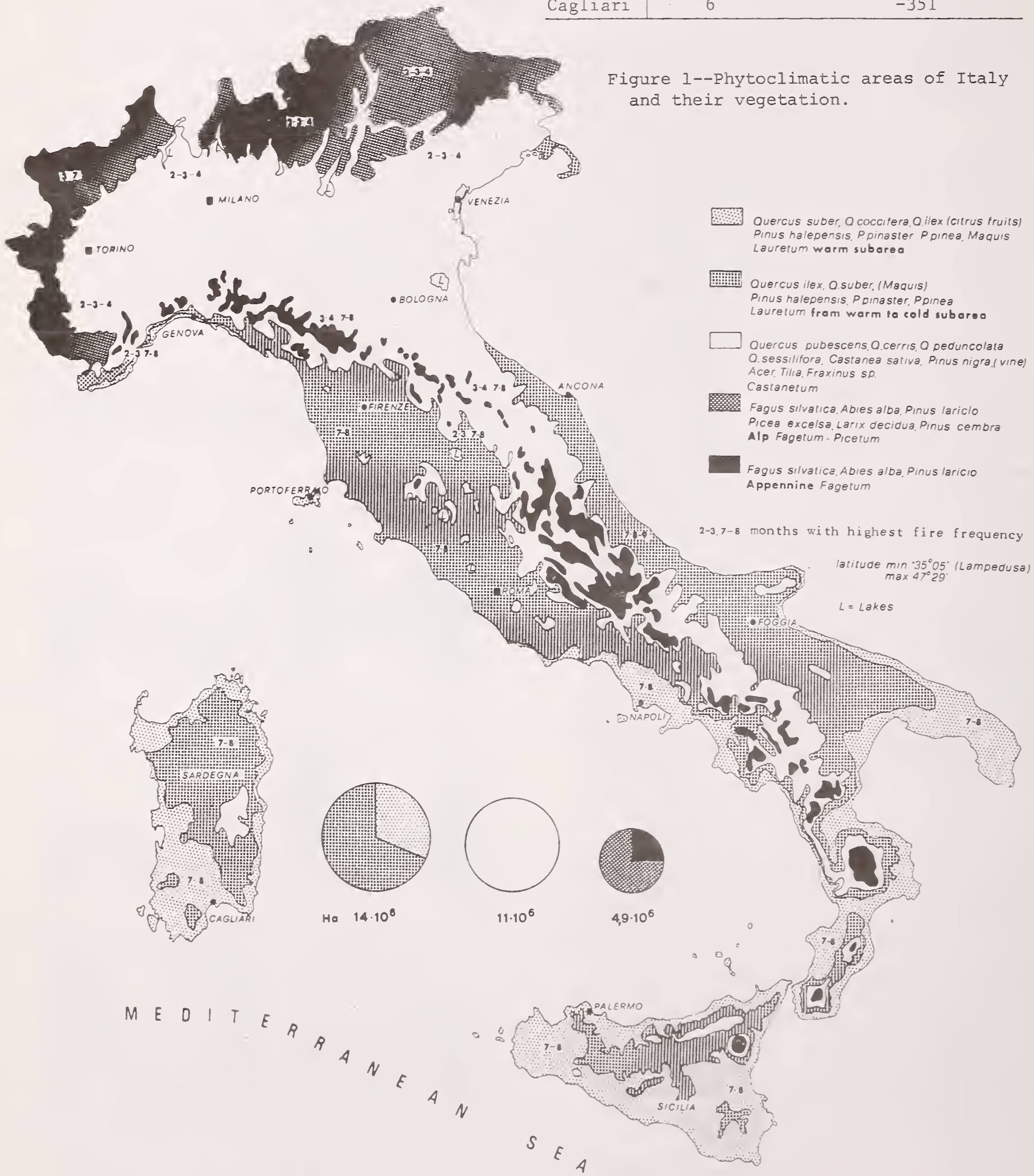

Figure 1--Phytoclimatic areas of Italy and their vegetation.

The potential water deficit may last 2 to 6 months for the middle-Adriatic and Ligurian regions and for the insular or extreme regions of the peninsula respectively; but a considerable water balance variability may also occur on scantly large territories. While rainfall unsteadiness from year to year seldom mitigates summer drought, it rather frequently protracts it till beyond Autumn.

But ecosystems are able to modify the effects of water stresses by means of the formation of soils with specific structural and hydrological characters (22).

The original soil of climax coenoses in the Mediterranean region (holly oak forests, cork oak forests, high and low maquis, etc.) was a Mediterranean brown earth, 100-200 cm deep, with good chemical, physical and biological characters. Now 20 to 50 cm of the upper soil are nearly everywhere degraded and eroded and sometimes almost swept away in consequence of the multimillenary human activity (23).

Among disturbance mechanisms are: the destruction of forests due to grazing and repeated fires; the accelerated mineralisation of denuded organic matter; destructive chemical and biochemical processes to the damage of humus and clay complexes; soil erosion worsened by grazing and fires.

Grazing action chiefly occurs in two ways: upsetting the humus horizon (swine) and decreasing soil protection from vegetation which is eaten (cows, sheep and goats). Besides, remarkably significant prove the consequences on humus formation due to the alteration of the qualitative composition in plant litter.

Conversely, fires have largely contributed, chiefly in the past (deforestation and soil tillage), to the destruction of the forest ecosystem, causing soil to suffer many effects:

- dissipation of nutrients in living and dead tissues;
- distruction of niches in the epipedon (modifications of pedobiologic spectrum);
- hygroscopicity reduction and increased soil erodibility;
- increase of soil texture and outcropping rocks.

Other noxious effects have been ascertained as fires repeated (at short or middle term): unsteady enrichment in minerals (in consequence of the incineration of organic matter) that is neutralized by overland flow, by leaching, by deep drainage and by erosion (lowering of adsorbing capacity); pH increase at the soil surface, decrease of organic matter, plant shift towards more and more xeromorphic vegetation patterns (3, 20).

On the ground of probabilistic surveys, experimental evidence has been reached in two Sardinian sites, with different vegetational aspects, showing that the pluviometric Mediterranean regimen and disturbed soil characters cause remarkable water deficits in summer.

In any case, it was observed both in grazed holly oak forests and in managed plantations that, during summer, only 50 mm rainfall can saturate mesopores in soils having 50% coarse texture, down to a depth of 100 cm.

Water soil conditions acting amidst and jointly with thermic conditions, affect plant physiology (metabolic, productive, phenologic cycles) and the pedobiologic populations and their activity, influencing the balance of the necromass and its biogeochemical cycles. Hydration degree of plant tissues, on which tissue flammability degree depends is also directly affected independently of species.

Cultivations in plantations, fire and grazing in the holly oak forest and in the maquis have reduced numbers of soil fauna (mites and springtails with scattered anellida and other worms) found abundantly in wet soil from October to May. It almost disappears (stops its activity) in summer months (22, 23). In spite of this fact, it has been shown that the necromass produced in the holly oak forest during one year is fully consumed at different rates according to the tissue quality. The metabolic stop in summer (4-5 months) is the cause of the accumulation of dead and dried tissues, a potential fuel reservoir.

The original plant distribution in low hills and plains of peninsular and insular Italy can be reconstructed on historical-evolutive grounds and according to the testimony of the few existing remnants.

The vegetation was characterized by evergreen sclerophylls (*Durisilvae*) of the *Q. ilex* belt, a xeromorphosis of the *Laurocerasus* subtropical mesophyllous belt (E. Schmid); also species from the *Q. pubescens* and *Quercus-Tilia-Acer* belts formed phytocoenoses, distributed at higher altitudes than the *Lauretum*, to a scanty extent. The ecological forms of the species in the *Q. ilex* belt show a subtropical origin: extensive lignification and ramification, annual growth, small-leaf evergreen crowns, roots with storage organs missing. Typical species are therefore xeromorphic (sclerophylls) and largely tree or shrub species. They share the following general physio-ecologic characteristics:

a) vegetative rest in the dry period;

renewed vegetational activity at the first rains with regrowth and sometimes a second blooming; possible winter pauses caused by frost; highest activity from March to May-June;

b) hydrostability, even during drought;

c) resistance to high temperatures which however are the cause of transpiration reduction and of photosynthesis;

d) considerable endurance of frost, that can lead to partial necrosis or death only when it is intense (-15°÷25°C).

Primitive coenoses were exclusively formed by forests, except where limiting factors (wind, extreme slope) interfered with tree vegetation. Among these: littoral forests-woods of wild olive, kermes oak, holly oak; forests (maybe non-autochthonous) of Mediterranean (stone and maritime) pines; coenoses of holly oak, tree phyllyrea, heather, strawberry tree; cork oak forests, that are also littoral. If we leave apart the high forests of the Mediterranean pines, of cork oak and of remnants of holly oak, actual coenoses are almost completely represented by coppices, moderately high woods, maquis either degraded or reduced to shrub garigues.

Holly oak forests

Some remnants (a few thousand Ha) of holly oak high forest are found in Sardinia (Supramonte di Orgosolo). They possess semi-natural characters and are an image of the original Mediterranean forest (23). Holly oak is dominant in the top and middle layers with rare trees of flowering ash and hornbeam maple and frequent *Juniperus oxycedrus* and *Phillyrea angustifolia*.

The presence of flowering ash and hornbeam maple (*Q. pub.* belt) and the absence of thermophil plants (wild olive and mastic tree) give this holly oak forest a mountain character that corresponds to the mesophil conditions of the forests of *Quercus ilex*. Here however, this type of vegetation is found in transition to the cold-damp horizon (climax of holly oak and pubescent oak, with *Taxus baccata* and *Acer monspessulanum*). Anyhow the most significant plants are shown in the following table.

Tree layer

Quercus ilex L.
Fraxinus ornus L.

Middle layer

Fraxinus ornus L.
Lonicera implexa L.
Arbutus unedo L.
Euphorbia characias L.
Rosmarinus officinalis L.
Thymus herba-barona Lois.
Paeonia russi Biv.
Crataegus monogyna Jacq.
Rubia peregrina L.
Acer monspessulanum L.

Herbaceous layer

Rhagadiolus stellatus Gaert.
Carex distachya Desf.
Geranium lucidum L.
Brachypodium distachyum P.
B. pinnatum P.
Dactylis glomerata L.
Luzula forsteri DC.
Satureja graeca L.
Allium subhirsutum L.
Asphodelus ramosus L.
Tamus communis L.
Cyclamen repandum S.et S.
Viola canina L.

Somatic structure-- The high holly oak forest (50% trees from seed, 50% natural suckers) shows an uneven-aged stand composition due to the space aggregation of groups of trees belonging to different time phases (young, adult and senile regeneration, etc.). These cover limited areas (200-600 m^2) already interpenetrating on small expanses (1÷2 Ha) (sometimes however they are separated even on comparatively large surfaces; 20÷30 Ha). In the overall stand constitution and composition the distribution of trees numbers follows a negative exponential law:

$$N = 146.218 \cdot e^{-0.311n}$$

(n is the number of (increasing) order of diameter classes 5 cm wide, starting from 17.5 cm), that identifies the state of normality. This is expressed as the function of the stature S (the average height of dominant trees), that is defined by the following relationships (19):

		for S = 17 m
K = decreasing coefficient	$= 3.5 : \sqrt[3]{S}$	= 1.36
N = nr trees/Ha	= 400(constant)	= 393
B = basal area (m^2)	$= 2.35 \cdot S$	= ∿40
V = unit cormometric vol. (m^3)	$= S^2 : 1,5$ (up to 3 cm diameter)	= 415
Ø = mean diameter (cm)	$= 8.7 \sqrt{S}$	= 35
Ømax = maximum diameter (cm)	= 5.6 S	= 90

the following parameters of ecologic structure correspond to the values above:

- total epigeal biomass = 340 t (d.m.)
- wood biomass = 310 kg (d.m.)
- leaf biomass = 7.42 t (d.m.)

Unit annual average production in a normal holly oak stand 17 m in stature (values in tons of dry matter/Ha) is:

wood	5.0	twigs	0.1
bark	0.2	epigeal total	5.4
leaves	0.1	roots	0.8

to which 1.0÷2.0 t acorn (dry weitht: 0.5÷1.0 t/Ha) should be added. On the average there is

a 15 t/Ha necromass on the soil, to which another 4.5 t add yearly. Litter is composed by: ± undecomposed leaves (45%); wood (fragments and twigs: 37%); acorn and cupules (3%); aments (5%); herbs and mosses (2%); minute debris(8%). These (summer) data are liable to variations according to meteoric events, phenological and physiological phases of holly oak. Holly oak vegetation activity, as a matter of fact,lasts all the year long, but it undergoes phases of varying intensity (fig. 3).

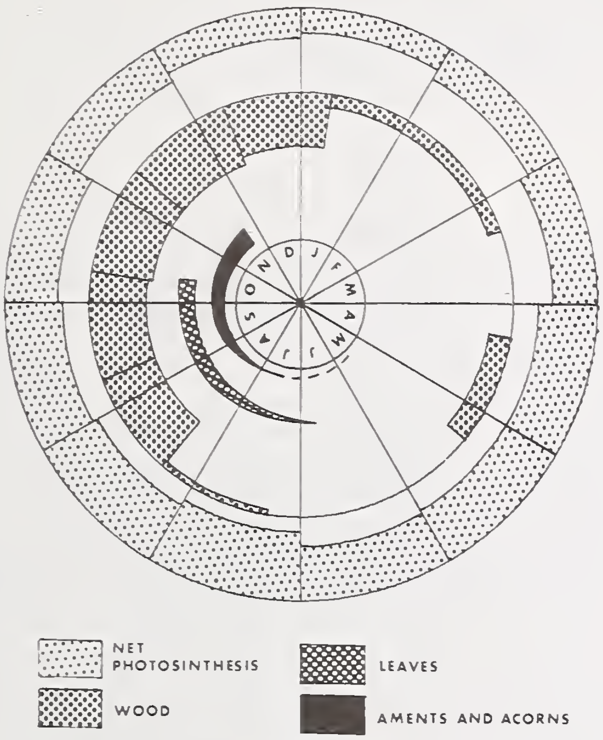

Figure 3--Vegetation activity in holly oak extends throughout the year.

Foliation starts in May÷June; growth is highest in September and stops in December. Leaves last three years (2÷5); their fall is progressive, continuous but irregular, with maxima early in summer and spring minima.Fruit sets in May÷June, after bud opening; it grows slowly (0.2 gr/month; max in September) in the second half of October; it falls in December to January-February.

Acorns feed many wild animals (jays, magpies, wood pigeons; wild boars, red squirrels, etc.), but chiefly tame swine (50 kg/Ha) that usually run wild in Sardinia and in other areas of the Mediterranean region (23).

Holly oak coppices

The plant composition of holly oak coppices resembles the high forest vegetation.Their biomass and wood production are averaged as follows (1):

age	high, m	total mass, t	total mean increment, t
10	1,6÷2,5	15÷25	1,5÷2,5
15	2÷4	30÷50	2÷3
20	2,5÷4,5	40÷70	2÷3,5
25	3÷5,5	55÷95	2,1÷3,8
30	3,1÷5,6	63÷112	2,1÷3,7

At Supramonte, on a forest site resembling a "shelterwood" coppice, there were altogether 3750 trees and suckers per Ha (diameter included between 1 and 86 cm; mean height 10 m), the epigeal biomass of which weighed 580 t. The necromass weight (65% twigs and leaves) was 15 t/Ha.

Cork oak forests.

Except for a few remnants, these vegetation types are not real forests, they are rather phytocoenoids without specific vegetational and structural characteristics, as they are specialized cultures. The cork oak culture however characterizes the forest pattern of some large Italian territories (for inst. Northern Sardinia).

Cork oak is more xero- and thermotolerant than holly oak, and tends to oust the latter on coast sites. Its normal plant composition is removed because of cultural purposes. It should be the same as in the holly oak forest, bu with more thermoxerophillous species (*Rosmarinus officinalis* L., *Juniperus oxycedrus* L., *J. phoenicea* L., *Genista corsica* D.C., *Phyllirea angustifolia* L., *Ceratonia siliqua* L., etc.). Unit biomass and production of cork oak forests can be averaged as follows (1):

age	nr trees	wood mass, t	average increment, t
20	860	25	1.20
40	500	60	1.50
60	390	115	1.90
80	315	170	2.15
100	240	205	2.05
120	170	215	1.80
140	115	203	1.45

Maquis.

These are the most widespread vegetation types of pyrophytes in the Mediterranean region where they have largely ousted the original forests. Together with holly oak and cork oak, sclerophyllous shrubs are dominant (*Arbutus une-*

do L., *Viburnum tinus* L., *Myrtus communis* L., *Pistacia lentiscus* L., *Erica* sp., *Spartium junceum* L., etc.). Present evolutive (man-influenced) conditions favour unpalatable shrubs with postfire vegetative and sexual regeneration. Also openings and glades are dominated by unpalatable annual (*Ranunculus, Asphodelus, Pancratium, Erodium,* etc.) and perennial plants (*Lavandula, Thymus, Cistus, Polygala,* etc.), that are either well supplied with high response ability to burning, as they can avoid its effects (geophytes), or with resprouting (for inst. several hemicryptophytes) and high dissemination mechanisms (a large number of chamaephytes and therophytes). Some of these plants, gathered in small colonies, find shelter from the browse of herbivores at the inner edges of dense shrub aggregations (for inst. *Plantago argentea* and *Brachypodium phoenicoides*). Biomasses and mean production, as a function of their age, can be summarized as follows (1):

age	biomass, t	average increment, t
2	2,5(1÷4)	2(1÷3)
5	10(7÷15)	2,5(1,5÷5)
10	30(20÷50)	3(2÷6)
15	40(30÷60)	4(2,5÷7)

To shrub biomass and production one must add the biomass and production of forbs and grasses amounting to 30 q (d.m.)/Ha/g (23).

Garigues and grasslands.

These vegetation types are formed by low shrub plants (garigues) or by herb and suffrutex species (grassland) with spring growth and autumn regrowth. The studies made (23) have shown that:

- there are two periods when growth stops, the former in winter (temperature fall) the latter in summer (absence of rainfalls: see climate);
- in autumn-winter, production depends on weather conditions (rainfall depths and frequence from summer to autumn). There is a period of slow growth from the first rains to the fall in temperature; winter growth stops when average temperature is lower than 5°C;
- regrowth (axis development and bud opening) varies according to climatic conditions and ecological valences of plants and not according to jont action soil moisture-temperature (water availability always sufficient). At first, growth is slow (thirty days), then very fast (two weeks), finally it keeps steady and declines (passing from the vegetative to the reproductive stage; three weeks). The rapidity of the second and the third period depends on temperature and the absence (shortage) of rainfall. Grazing can alter the succession of the growth stages protracting the first, reducing the intensity of the second and, possibly, preventing the third from occurring.

Also plant composition and biomass vary with these factors; steppe types (dry and hot coast areas) gradually turn into shrub grassland (internal areas and hills) and maquis (sites with better soils and more available moisture). According to studies carried out in Sardinia, the biomass corresponding to the maximun production for grassland varies from 0.1 to 10 t, d. m. (the worst and the best site conditions).

Management trends

Serious as the problem has been for such a long time the defence against fires has hitherto been limited mainly to the enforcement of legislative measures of a negative or coercive nature defined by the forest ordinance of 1923 nad by subsequent laws that referred to the Police or other provincial and town regulations. These regulations made fire control hardly feasible as they did little more than make it a duty to report fires (in several areas there were in fact lookout posts and towers) and did not contain provisions concerning organization or the remuneration and insurance of workers.

In favour of the fire control service, the forest inspectorates, on whose individual initiative depended both prevention and suppression, could not divert to a sufficient extent either personnel or the modest means at their disposal because they were already overburdened with their other institutional tasks. Such a state of inefficiency can partly explain the marked increase in the number of fires since when, starting from 1960, forests and maquis have suffered the bursting assault of tourism and construction development (table 1). Urged by public opinion and pressed by the forest service, public powers were forced to face the problem; consequently, the national law nr 47 regarding the "integrative regulations for forest fire control" came into force in March 1975 (9 and 7 years after the French and Spanish laws respectively). The law was conceived with highly innovating criteria and provides for essential technical measures, also taking into consideration, on a local scale, the past causes of the problem and its implications, both of social, political and economic nature. Though fires cannot be completely avoided, the marked increase in their number during recent years (table 2) is on the other hand due to the changed social habits, to a feeble and confused protection of natural resources, to the poor efficency of the administrative bodies, and to the scanty civic and

ecologic education of the public (table 1). The problem of fires, within this general frame, meets with conditions of further deterioration in the land utilization, which resembles a thick mosaic of urbanized agricultural, grazing and forested areas, the latter being almost everywhere fragmentarily spread on small strips.

Table 1 -- Fire causes in Italy (Ministry of Agriculture and forests, 1976).

		number N	%	area burnt Ha	Ha:N
natural	1965	24	1	200	12
	1975	65	1	1100	17
unintentional	1965	746	32	6100	8
	1975	2345	38	29200	12
intentional	1965	184	8	3000	16
	1975	886	15	12400	14
unknown	1965	1366	59	14200	10
	1975	2796	46	28700	10
total	1965	2320	100	23500	10
	1975	6092	100	71400	12

Unintentional: burning for cleaning fields and refuse, tourists, negligence, etc.

Intentional: speculation, terrorism, shepherds' fires, revenge, incendiarism.

Table 2 --Number of fires (N) and area burnt (Ha) in Italy (1961-74) (Forest Service).

years	N	Ha	Ha:N
1961-63	9,180	119,703	13.04
1964-66	8,780	94,968	10.82
1967-69	9,237	87,188	9.44
1970-72	15,394	169,823	11.03
1973-74 (31/8)	9,845	196,575	19.97
1961-74	52,436	668,257	12.74

Forest area burnt ≃ 2/3 of the total burnt area

1961-74 forest area burnt ≅ afforestation + forest reconstitution

Ha burnt in the Mediterranean climate ≅ 2/3 of total burnt area.

It appears therefore that priority should be given to the criterion to keep forest areas apart from others, bearing in mind the difference of political, economic and technical solutions that are implied in fire control practice.

In fact fire control can be effected indirectly in the case of pastures (turf improvement and yield increase) and forests (bringing them to the normal state, chiefly in their density); it can be effected directly in urbanized and forest areas with fire control measures (equipment). In the forest field the final model, whereever feasible, is the holly oak ecosystem of sufficient maturity, as already stated. Such a forest preserves the moisture and reduces shrub and herb underwood growth and, thanks to the steadier and cooler bioclimate, makes litter decomposition more regular, preventing its accumulation.

However, as the attainement of the objectives that can be secured indirectly requires middle or long times, direct fire control measures must be promptly put in action. Means and men should be placed at disposal without delay in order to carry out the strategy, already tested in the Mediterranean area (17, 10, 9), and articulating of four series of co-ordinate short-term measures:

- prevention (information, education, watch) intended to reduce fires starting;
- ready detection of fires and the prompt report to allow the quickest suppression interventions;
- installations on the terrain, to be arranged by adequate regulations of forest management, by dividing forest areas into separate blocks (firebreaks), by opening access roads, by the construction of water reserves, of operational bases and of landing grounds for helicopters;
- suppression with water or water mixtures of chemicals making use of ground and air equipment.

The new law offers this possibility. In fact the districts (superprovincial bodies into which Italy is presently divided) are bound to plan the protection of woods and maquis against fires, the conservation of forests and the reconstitution of burnt forest areas. Interventions must be planned for ecologically homogeneous areas. Expenses are supported in full or partly (75%) by the State.

Starting from the study of the ecological factors that affect fires (weather, meteorology, vegetation, soil) and integrating them with the factors that regard the social-economic conditions (the type of economy, development degree, income, tourism, town-planning, etc.) and fire parameters (number, area burnt, duration, space and time partition, distribution according to vegetation types; causes), plans must draw the fire danger map, where areas of more or less potential danger are identified. This will be of use both for deciding where efforts should be focussed and for giving suitable arrangement

and strength to the fire control service, utilizing measures, structures and infrastructures already existing.

The organization of the service should be planned on the grounds of these elements, both detailing preparations on the terrain (road network, water points, firebreaks, equipped lookout stations, headquarters and networks of radiotelephones, sheds for power equipment, mobile equipment and chemical retardants, bases and equipment for fire control, squads, heliports, etc.) and defining the regulations of coordination to secure the effectiveness of the fire control organization. Preparations on the ground also include cultural interventions on the vegetation (firebreaks, cleanings, thinnings, etc.) and management measures to reduce fire risks.

While the fire control service falls under the responsability of local political Authorities, State or District Foresters, who supply the organizing staff and manpower, are entrusted with its management, coordination, study and propaganda; foresters are assisted in their prevention activities by forest workers and in suppression operations also by equipped, duly remunerated and ensured squads of volunteers.

The ways, the technical times and the priority order to be followed in order to put all these measures into effect, along with the estimate of required expenditure, represent the third part of the plan. This is obviously intended for programming, and must be accomplished and carried out in five years' time (1975-1979), at the end of which the same plan will undergo revision and, if necessary, modification.

As to mobile terrain means, the use of road and cross-country vehicles, lane cutters and bulldozers, tank trucks, pipes, power-driven brush cutters, power saws, swatters, fire-fighting overalls, gas-masks, etc. is planned; as to air means the use of helicopters for aerial detection and report, but chiefly for active fire-fighting with the transport of manpower, tools and tanks of water and water mixtures of retardants to be dropped on fires is planned.

In addition to the hard integration of such measures in their natural political, economic and social frame, the other prominent feeble points of the law are represented by the scanty financing (13 million dollars in 1976) and by the shortage of technical personnel, whose strength is formed by State and District foresters (on the whole 6000 men, 700 of whom are inspectors, 2000 warrant officers and 3300 guards) for whom no increase in number is considered by the law. However, the cause of the problem is not only the number, but chiefly the technical efficency of the personnel, both at the organizing and at the executive level: only for the latter the law foresees the formation of highly skilled motorized units, to be trained at the school of forest warrant officers at Cittaducale.

All good intentions of the law will hardly be carried into effect to the necessary extent and within seasonable time because there is not only a lack of financing means but also a want of men and experience. A positive fact is that, after so long indolence and resignation, there is now a legislative instrument capable to lay the grounds of a modern fire control service. It should be developed following the suggestions and the experiences contained, at an international level, in the "Proposals for a global Programme" prepared in collaboration between UNESCO and FAO by Carl C. Wilson (1975; 26). In this connection there are examples of a few Districts that, as has been mentioned, have preceded the State with their own laws by some years (Piedmont, Lombardy, Venetia, Friuli-Venetia Julia, Umbria, Latium, Campania, Apulia) and of some others, that, though any organic legislative instrument was lacking, have nevertheless operated without waiting. On the contrary, they have supplied models that the Italian State has made use of in the legislative seat. Among these, the most significant Italian model is presently the one of the Autonomous District of Sardinia (21).

In Sardinia the fire control service was established in 1951 according to past views and it started to develop on new grounds in 1973, when chemical retardants appeared. In the following years increasing use was made of helicopters (4 in 1976) and firebreaks; lookouts, radiotelephones; tank trucks and equipped land rovers and mechanical extinguishers were increased. Presently there is a 50% deficit for water points, retardant storages, repeaters, heliports and for some vehicles (tank trucks and cross-country vehicles, if compared with the theoretic needs. Instead, the 5-6 average-power helicopters (LAMA SA 315B) already employed should meet all needs.

Also in Sardinia, fires have undegone an increase in the last years (3000 fires and 200,000 Ha of area burnt from 1960 to 1973, 1/4 of which occurred in forests and 3/4 on grazing and shrub areas), where 80% are shepherds' fires. Therefore it is shepherds that represent the most dangerous fire threat for forests and maquis and consequently it is on these areas the fire must be fought. However, as yield amelioration of pastures will demand a hard psycological adaptation from

shepherds, it is imperative to secure the protection of wood and maquis against fires in the best way.

That is why the strategy of the local fire control service is being planned in a structure (fig. 4) of "light" interventions, taking advantage, to this purpose, from the extensive road network available (on the average 43 km/100 km^2). Such a structure is

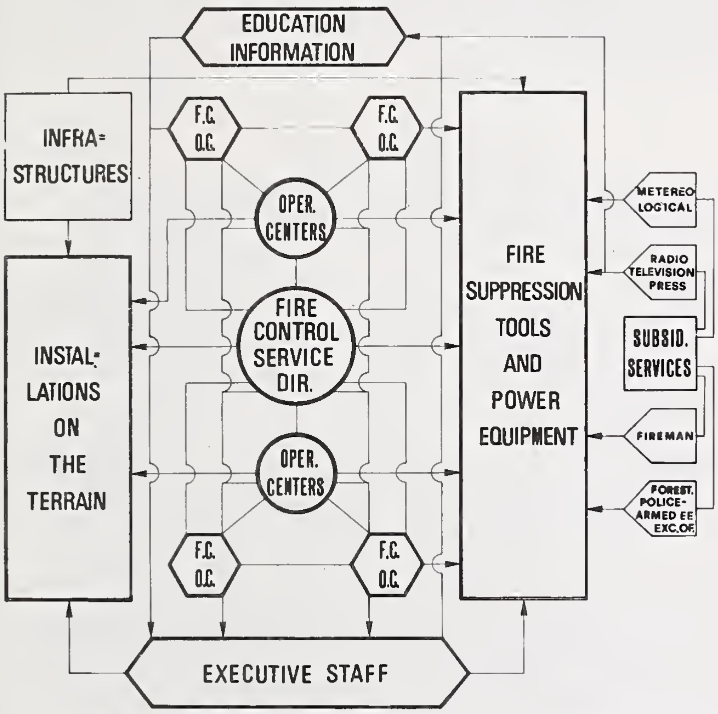

Figure 4--Model of fire control organization in Sardinia.

intended to reduce times from detection to suppression action as short as possible, and to stop fires at an early stage. This is the object of the main efforts, as it appears from the development of lookouts, on the radiotelephone net, of water points, of ground and air means and of the organization of the personnel. As a matter of fact, the use of helicopters in 1976 according to a method tested during the two previous years in the province of Nuoro, that is the most advanced in the field, has made it possible to achieve the following results (on 238,000 controlled Ha):

		fires, nr	burnt area, Ha	average area/fire,Ha
average	1970-73	750	10,000	14
"	1974-76	600	5,000	8
only	1976	570	2,200	4

Such a strategy proves the most efficient for suppressing fires at their very start. But in order to fight large fires this strategy must consider both the necessity to divide the few most extensive areas into compartments by means of firebreaks, and the need of a sufficient equipment of high power means. As artificial firebreaks are not far from the upper development limit, further possible action chiefly depends on the strengthening of heavy power means (18).

The same criteria so far related can also apply to other districts, bearing in mind of course the logical variations. However, owing to the reasons mentioned, the evolution in Italy in this direction will be rather slow as it is shown by the fact that two years after the enforcement of the law the figures are more or less the following (the % refers to the number of Districts that have carried the foreseen measures into effect, and not to their extent that corresponds only to a small fraction of their actual needs):

<u>prevention</u>:
- information and education 30%;
- firebreaks and water points 50%, chiefly in the North, except Sardinia;
- controlled burning 20%, only on firebreaks and sometimes in counterfires, generally with positive results;

<u>suppression</u>:
- lookouts 50%, equipped with binoculars, maps and radiotelephones;
- vehicles 100%;
- tank and pump trucks 30-40%;
- helicopters 20%;
- firefighting squads 70%, chiefly of volunteers amounting altogether to some 12,000 men, 1/5 of whom are in the South.

The highly fragmentary distribution of forests and maquis, the country area and its 4/5 mountain-covered morphology along with the shortage of water reservoirs, the necessity of suitable airport equipments and their cost make the use of aircraft problematic. In Italy preference has so far been given to middle power helicopters, that have given good results, as has been seen. In any case, if some major obstacles were removed, the use of water bombers could be tested in a pool with other Mediterranean countries, in addition to other suppression means.

Prescribed burning is not considered by the law among prevention means, even if burning is employed in some cases to clean firebreaks, while counter-fires are used in other cases. A multi-millenary experience shows that burning, with grazing and agriculture, has caused serious desertifications, which often prove irreversible and still now it often causes a block of degraded ecosystems preventing them from reaching more evolute patterns (20, 13). Therefore it was not by chance that, during the consultation FAO/UNESCO at Provence-Langue-

doc in May 1977, all participants unanimously approved the recommendation to make use of controlled burning with the greatest prudence in those areas where no exact information on soil evolution and vegetation responses is available. On the other hand, the same resolution recommended to spread the favourable results obtained in the use of prescribed burning from interdisciplinary research in France (24), Greece (8), Israel (14, 15, 16) and Spain, to other countries. The practice of spreading the results of prescribed burning for different purposes has long been followed, for inst., in the United States (7, 2, 11) and in Australia (25) (chaparral management, forest regeneration, etc.) (12).

Keeping to the Mediterranean region only, the different positions towards the two trends - for and against prescribed burning - depend, as far as we know, on the different aims pursued. Should the final aim be the close and dense forest, capable of self-preservation, then in general prescribed burning could not be recommended. On the contrary, if a pastoral aim is pursued, controlled burning can prove a useful tool - although not all opinions are the same on this measure (4)-to direct the evolution in the way expected, even if significant natural or artificial plant replacements may occur. Since - apart from risks and costs - prescribed burning is always the cause of alterations in soil and vegetation, the former model is intended to avoid all risks in order to favour the evolution of the Mediterranean grasslands and maquis towards the holly oak forest. The major - but not exclusive - reason for this policy is the protection of the environment by means if less flammable and stabler forests. Conversely, the latter model does not take into consideration the possibilities of evolution for maquis and grasslands and, being worried about more economic reasons, suggests the replacement of these vegetation types by forage-crop types that are not ecologically mature, while proving more flammable in the dry season. Leaving apart any generalization, both models can - on principle - be supported by valid reasons. It is only on the ground of strict researches and long experiments that the integration between the two logical and operative trends should be approached case by case, as a function of ecologic, economic, social and technical factors that vary from one area to another (23).

In conclusion: the problem of vegetation fires in Italy and consequent dangers for the biological balance and the physical stability of the environment has only very recently penetrated into the mind of a fairly large public. When considered in absolute terms the problem is very modest in comparison, for inst., with the United States or Canada. However, the problem is serious in relative terms if one considers the shortage of forests and maquis and the impairment of the land, mainly in the area with Mediterranean and sub-Mediterranean climates, where fires amount to 2/3 of their total. The legislative and technical instruments, that so far had been missing in order to make up for such a critical situation are to day available. However, fire management problem must be faced as carefully as possible if damages are to be limited in time to an admissible extent.

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THE EFFECTS OF FIRE ON THE VEGETATION OF DOÑANA NATIONAL PARK, (SPAIN)[1/]

FRANCISCO GARCIA NOVO[2/]

Abstract: The vegetation of Doñana National Park (S. W. SPAIN) is described in relation to climate, and geomorphology.

Fire occurrence in the area and fire management is discussed in relation to vegetation.

Plant succession after scrubfire is described both for annuals and for perennials showing a 5 stage process that takes 10 to 25 years to be completed.

Present day distribution and numbers of the existing tree species are discussed in relation to biotope and fire effects.

It is concluded that present day scrub of Doñana National Park is a stable type of vegetation derived and maintained through repeated fires.

Prior to scrub development Doñana area was covered with a forest dominated by cork oak (*Quercus suber*) together with wild olive tree (*Olea europaea*), strawberry tree (*Arbutus unedo*) Kermes Oak (*Quercus coccifera*) and with junipers (*Juniperus phoenicea*, *J. oxycedrus*) on drier ground.

Key Words: FIRE, MEDITERRANEAN VEGETATION, SCRUB, FOREST, SUCCESSION.

Quercus suber. *Quercus coccifera*. *Olea europea*. *Artutus unedo*

1. The Doñana Area

Doñana area covers some 1000 km^2 of coastal lowlands in the Gulf of Cadiz (S.W.Spain). Half the area corresponds to marshes derived from the ancient Guadalquivir River estuary; the other half is an ancient (pleistocene) coastal plain covered by more recent sand dune systems. Doñana Area includes Doñana National Park, with an extension of 360 km^2; world renowned for its rich fauna where the effects of fires on vegetation have been carried out. An ecological description of Doñana may be found in GONZALEZ BERNALDEZ et al. (1977)

2. Geormorphology

In the dune plain two main landscapes may be distinguished: the stabilized sands and the mobile dunes. The stabilized sands are very large transgressive dunes, several km long, partially eroded by wind and rain, now reduced to a series of arched low ridges (locally "naves"). Between ridges, there are flat depressions corresponding to the "slacks" of the original dune formation, where temporary shallow lagoons develop.

Substrates are uniformly sized eolic sands (0,2-0,5 mm) (IGME,76) largely composed of

1/ Presented at the Symposium on Environmental Consequences of Fire and Fuel Management in Mediterranean Ecosystems, Palo Alto, Calif. Aug. 1-5, 1977

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quartz and with no calcium carbonate. The "mobile dunes" include a complex of massive transgressive dunes up to 2km long advancing inland at a steady rate of 5-6 m per yr. (GARCIA NOVO et al., 1975). The system, that extends parallel to the coast for some 30 km has undergone no less than 7 development stages each associated to a prevailing wind direction (POU ROYO,1976).

A general description of the area may be found in VANNEY (1971). The mobile dune sys-system has been studied by GARCIA NOVO et al. (1975), ALLIER et al.(1975), ALLIER et al. (1974).

3. Climate

Annual precipitation averages 550 mm with a winter maximum of 90 mm in Nov-Dec and a secondary maximum of 85 mm in February-March. Summer drought is severe with precipitation on July-August and only 24 mm average for June. Summer drought is coupled with high temperatures (average mean temperatures are: June 20.5°C, July 23.9°, August 23.6°C). Winters are comparatively mild with average mean temperatures of 9.3°C for the coldest months (January and December). Both maximum and minimum temperatures are milder than would be due to oceanic influences; temperatures below freezing point are rare. A discussion of climatic features of the area may be found in Merino et al.(1976).

4. Vegetation

Both stabilized sands and mobile dunes are now covered with forest, and matorral (scrub). In the stabilized sands, pine (Pinus pinea) forests were seeded in the early 40's. The other important tree is the juniper (Juniperus phoenicea) that forms an open forest in driest substrates (elevated old ridges) of the stabilized sands. Other tree species include cork oak (Quercus suber). Kermes oak (Q.coccifera), wild olive tree (Olea europaea var sylvestris) Strawberry tree (Arbutus unedo), poplar (Populus alba), ash tree (Fraxinus ornus), tamarisk (Tamarix africana). They all form small patches or are represented only by isolated individuals. The reasons for this scarcity of trees will be later discussed.

Mobile dunes present natural vegetation of pines forming dense stands in the slacks between dune fronts. Juniperus phoenicea will only colonize relative stables sands, while Juniperus oxycedrus ssp. macrocarpa is limited to stable ground under definite oceanic influence.

4.1 The matorral

The "matorral" (scrub)[3/] is the predominant vegetation type of Doñana stabilized sands. Its species composition is fairly rich and it appears to be controlled by soil topoggraphy, through the distance to soil water table (GONZALEZ BERNALDEZ et al., 1976). Species living on drier, more elevated, ground as Lavandula stoechas,Thymus matichina, Rosmarinus officinalis,Cistus libanotis withstand during summer drought, very negative water potential in their leaves (MERINO et al, 1976). Matorral species living on low ground are Erica australis, E.arborea, E.ciliaris, Calluna vulgaris, with Myrtus communis, Phillyrea angustifolia, Erianthus ravennae, and Cistus salviaefolius. Those species cannot withstand in their tissues large negative values of water potential; their distribution is therefore restricted to those areas with available water during summer drought. (Water table not deeper than 1 m.)

5. Fire history of the area

Due to poor sandy soils, the area was of little agronomic value; at least since the XIII century it has been managed as a game Reserve due to its rich fauna that has been preserved today. However the management of the area has included shifting cultivation, lumbering (pine and juniper), charcoal burning (ash), cork and pine cone collection, cattle (cows) introduction, and especially, fire.

Fires break out throughout the area in summertime. It is useful to distinguish between two types of fires: Minor fires and wild fires. Minor fires (1-10 ha range) break out once or several times a year. Whether accidental, or intended to clear a patch of matorral for grass they are kept under control.

More rarely (once every 15 years as an average) a wild fire breaks through accident or careless fire control. The surfaces affected by those wild fires greatly differ (100-1000 ha or more) but in any case they are very intense as compared to minor fires. Those wild fires may also spread through the marshes, after they dry up in summer, with fronts several km wide. The mobile dunes however are relatively protected from fires because the sand dunes act as natural fire-breaks.

3/ We agree with SAUVAGE (1961), TOMASELLI (1976) and others that "matorral" is a valuable term for describing the large scrub cover, so common in Mediterranean areas.

No records of fires in the area prior to the beginning of this century have been found. However ecological evidence strongly suggests that fire has been a dominant environmental factor in Doñana area for at least two centuries.

THE EFFECTS OF FIRE ON THE VEGETATION OF DOÑANA

6. Effects on matorral species

Fires spread rapidly through matorral, and plant burning is usually limited to leaves and thin branches.

Apart from meteorological conditions (air temperature, wind), duration of the previous drought, moisture content of fuel, fire spread depends on fuel accumulation. The threshold for Doñana area has been evaluated at 0,5 kg m^{-2} plant material; under this value the fire ceases to propagate in windless conditions. On the other hand, as grass cover is almost non-existent under matorral and fairly short even in grassy areas those will act, together with bare sands (dunes, ridges) as natural fire-breaks.

Fire affects leaves and thin branches of plants only; however for most plants this will kill the aerial parts or the entire plant in the case of sensitive Halimium halimifolium that is equally killed by hot air without being affected by flames.

The recovery after fire is highly variable, depending on the species characteristics, some of which are summarized in table I. Besides, the water availability, nutrient mobilization, animal interference (grazing) and time of the season (after a drought fires are much more devastating) all affect post fire plant recovery.

7. Post fire succession

Early stages of post fire succession are largely dependent on meteorological conditions, but further on the process will become more independent. Although both herb and woody species grow together, it is convenient to separate grass and matorral succession. Data presented here have been collected in a series of identified burnt areas where precise dating of fires has been possible. Both permanent transects along recently burnt areas and sample plots on areas that have been burned long ago have been used. Quantitative data of plant cover, plant density, biomass, species diversity and soil analysis of plots may be found in MARTIN VICENTE (1977).

7.1 Grass Succession

Grass succession lasts for about 5 years after fire; after that time matorral tends to grow too much and to alter the process. The dominant environmental factors controlling grass succession are nuturient and water availability; water table depth is thus indirectly related to the process.

During the first year, only a few species make an impressive growth, but soil cover is still low but for very wet areas. Carlina corymbosa reaches in the first year its maximum number (and size). Senecio jacobea is also important but it will not reach its maximum until the second year.

Anthemis cotula, Ornithopus pinnatus O. sativus, Reseda media, Centaura exarata, Vulpia spp., Briza maxima, Loefflingia baetica, Illecebrum verticiltum, Evax pygmaea, Polycarpon teraphyllon, Anthoxantum ovatus, and Brassica barrelieri all increase from 1st to 2nd year reaching the maximum development in the 3rd year, decreasing as matorral species develop. On wet areas, Myosostis spp, Mentha pulegium, Anagallis arvensis, Panicum miliaceum, samolus valerandii, and Ranunculus baudotii are dominant at this stage.

In the 4th-5th year all those species decrease due to matorral development and herb species that grow under matorral plants will attain maximum development, slowly decreasing afterwards. Those species associated to matorral are: Tuberaria guttata, Erodium cicutarium, Plantago psyllium, Malcolmia lacera, Rumex bucephalophorous, Ononis subspicata and Crassula tillaea.

7.2 Matorral succession

As mentioned above, matorral composition depends on soil topography through distance to water table. This environmental factor also controls the process of succession that will also depend on fire duration and intensity and meteorological conditions affecting plants. Generally speaking, the deeper the water table, the slower plant succession will take place.

Summarizing data for intermediate ground locations, water table 1 to 2 m deep) this picture emerges: 1st stage: 0-3 months. No seed germination. No annuals. Resistent species recover after fire. Two species show an outstanding recovery: the dwarf palm Chamaerops humilis and Daphne gnidium. The fibrous stems of the palm are hardly affected by fire. Immediately after, injured leaves keep growing and new ones will appear.

Table 1--Responses to fire of 12 matorral species of Doñana area.

Species	Inflamability	Regrowth	Germination After fire	Other Comments
Erica australis	good	good	good	Regrowth depends largely on water availability
Chamaerops humilis	very poor	very good	good	Immediate growth after fire
Daphne gnidium	poor	very good	poor	Immediate growth after fire
Osyris lanceolata	good	nil	poor	
Stauracanthus genistoidis	good	very good	good	Repeatedly eaten for herbivores during regrowth
Halimiun halimifolium	very good	nil	very good	Extremely high
Halimium commutatum	very good	nil	good	
Cistus salviaefolius	good	nil	very good	Strong increase in germination after fire
Cistus libanotis	good	nil	good	
Ulez minor	good	very good	good	Good regrowth but very slow
Scirpus holoscheonus	good very good	good		Good regrowth if available water
Juncus effusus	good very good	good		Good regrowth if available water

D.gnidium although losing all branches will start, immediately after fire an impressive growth producing new branches up to 70 cm long during the first 3 months. Growth rate will slow down from then on to 20 cm per year. 2nd stage: 1 year. Both matorral and herb species seeds germinate. Fire resistent species restart growth.

Stauracanthus genistoidis grows very easily from its thick base. Erica australis, and E. arborea will also grow from the base only if there is a large amount of available water. Ulex minor will also grow but it will take much longer to start. Those species with subterranean organs such as Urginea maritima, Pteridium aquilinum, Scirpus holoschoenus, Scirpus setaceus, Juncus maritimus, J. effusus will grow easily after the rainy season; apparently they are favored by fire due to increased nutrients availability and limited competition.

Halimium halimifolium will not resprout again but it will germinate in very large numbers after fire. Cistus libanotis, C.salviaefolius, Osyris lanceolata, Lavandula stoechas, and Rosmarinus officinalis, Rubus ssp. all follow a similar pattern. It is interesting to mention that seedlings of these species are very hard to find in the matorral under normal conditions and their seeds germinate very poorly (under 1% for Doñana collected seeds, COTA GALAN, unpublished) suggesting that for those species (especiall H. halimifolium) establishment is markedly favored by fire. 3rd stage: Intense growth for most species. No germination of seed from matorral species.

At this stage, species germinating from seeds and species making regrowth from their base of other subterranean organs, make steady growth. Pteridium aquilinum will reach now its maximum growth, decreasing afterwards. Chamaerops humilis and Stauracanthus genistoidis tend to make

little progress due to heavy damage from herbivores: as primary producivity is much lower after fire, consumer pressure tends to concentrate on edible species.

Rubus ssp. will maintain fast growth if high nutrients and water were available; otherwise, it will slow down about the 2nd year. Cistus salviaefolius will grow very well in sheltered places only. In the open it will do poorly after germination until other species provide some protection. 4th stage: 3rd to 4th year. Large increase in scrub species. Matorral composition evolves towards mature mattoral types according to topography variations. Herb layer declines.

On those areas with water table 0, 5 to 1 m deep, a dense Erica cover develops. Calluna vulgaris will be added from seeds as E.rarennal and others. Phillyrea angustifolia and Myrtus communis will slowly grow. H.halimifolium if present will be excluded at this stage. Cistus salviaefolius will persist for a longer period until the Erica stand makes a very dense cover. On higher ground (1-3 m deep water table), Halimium halimifolium and Stauracanthus genistoidis dominates. If sheltered, Cistus salviaefolius and even Calluna vulgaris will be present. On higher or more exposed locations, Helychrysum italicum and Rosmarinus officinalis will also enter.

Finally, on higher ground (over 4 m above water table) Lavandula stoechas, Cistus libanotis, Halimium commutatum, Thymus mastichina will be present; Halimium palimifolium will be scarce or non-existent. 5th stage: from the 5th year onwards. Matorral recovers its original composition and structure.

Erica matorral is indistinguishable from a mature stand after a 10 year interval, if water supply is favorable. Otherwise, slower plant growth will take place. However, in all cases examined, after a 13 year interval there will be full recovery of this matorral type.

Lavandula matorral on higher, much drier ground shows a more slow recovery. After a 10 year interval, matorral composition is approximately the original one but plant cover and plant size are much smaller. After 15-20 years differences are noticeable to the eye but they may still be discovered with aerial pictures or ground measurements.

Summarizing this evidence, Doñana matorral appears as a Mediterranean type of vegetation well suited to local biotope characteristics (poor sandy soil, fluctuating water table). This is only partially the case. In fact, Doñana matorral is a case of fire selected and fire adapted natural vegetation that bears little resemblance with the original mediterranean forest from which it derivates. The discussion of the distribution patterns of tree species belong to the original forests will shed light on the process of transformation.

8. Patterns of distribution of tree species.

On the stablized sands of Doñana, trees are few and they grow in scattered patches with the noted exception of pine plantations. With the exception of Juniperus phoenicea stands over the ridges, no original forest exists today. However, 10 tree species present in the area suggest that various types of tree vegetation existed in the area forming a forest which composition, extension and causes of disappearance we can only guess.

We will discuss existing vegetation types to concentrate our interest on the distribution and composition of the cork oak forest. In the dunes three species (Pinus pinea, Juniperus phoenicea, J.oxycedrus) will tend to form definite forest types depending on sustrate stability: mobile dunes exclude junipers supporting only the local Pinus pinea ecotype. Juniperus phoenicea will colonize dry stable sands and J.oxycedrus will spread only on stable sands with favorable microclimate open to oceanic influence.

Tamarix africana agr., Populus alba and Fraxinus ornus, together with species of genus Pirus and Salix may have been present in floodable areas, including river banks, and the border of lagoons. The sandy borders of the marsh may have represented a definite location for all these species: Tamarix africana growing directly on floodable areas. Populus alba on wet depressions and Fraxinus ornus on the sandy plains that border the marsh, Salix was probably limited to unstable banks associated to the drainage network.

By and large, the stablized sands forest has been free of above species; the trees in it were cork oak (Quercus suber), Kermes oak (Q.coccifera), wild olive (Olea europaea var sylvestris) and strawberry tree (Arbutus unedo). The ecology of these four Mediterranean species is different (TOMASELLI, 1976; RUIZ DE TORRES, 1971). Their presence together in the same forest type suggests a semiarid to subhumid peculiar thermic microclimate of thermic character with a

net oceanic influence. Sheltered, more thermic situations will have wild olive together with Kermes oak in thermic but dry locations. Strawberry tree might have been common in watered locations open to oceanic influence; cork oak probably was the main component of this forest over the area; it may be substituted by wild olive, and Kermes oak with Pistacia lentiscus and Chamerops humilis in more sheltered thermic areas, and for Juniperus phoenicea and J.oxycedrus dry substrates open to oceanic influences. The coexistence of thermic and oceanic species in Doñana confirms the peculiar equilibrium of this climate that allows species of different requirements to live together. This peculiar equilibrium allowing for maximum diversity has also been singled out in the case of matorral for MERINO et al (1976) and ALLIER et al (1974) and for the fauna in VALVERDE (1960) and HAEGER et al (1976).

DISTRIBUTION PATTERNS OF THE MAIN TREE SPECIES

9. Observed patterns of distribution of tree species.

Limiting the survey to the more important species (Kermes oak, wild olive tree, strawberry tree and cork oak) their distribution on the stabilized sand is thus: Kermes oak (Quercus coccifera). It is a very scarce species. Some 10 shrub type individuals are found around temporary lagoons. Another 4 tree-type individuals (some 5 m high) were found inside a very thick Erica matorral close to a temporary lagoon near the "Pinar del Rasposo".

Wild olive trees (Olea europaea) occur either as isolated big old trees with very large crowns (5-8 m across) or as shrub-type plants 1-2 m wide. Old trees are isolated and they usually are close to a temporary lagoon. Some 20 shrub-type plants occur together in a reduced area (about 5 ha.) of the stabilized sands close to the boundary with the marsh.

Strawberry tree (Arbutus unedo). It is also a very rare species in the Doñana National Park. Two enormous isolated trees and a dense patch of big trees growing together with cork oak at Encinillas Altas. All Strawberry Trees are very large 12-15 m high with a dense crown. No young trees have been observed.

Cork oak (Quercus suber). There are about 400 cork oaks left in Doñana National Park in the stabilized sands, and most of them are located in the "vera" ecotone between the stablished sands and the marsh forming a Savannah-type forest. Other cork oaks are spread all over the stablized sands complex, but mostly in the lower ground. Their preferred location is close to a temporary lagoon border as isolated trees or as a small group (2-3). Most trees are very big up to 20 m high and with crowns up to 15 m across with very long branches bending down almost to the ground. Another patch with some 10 big cork trees growing together with strawberry trees at Encinillas Altas, has already been mentioned.

10. Discussion of distribution patterns in relation to fire effects

No sample of the original Doñana forest is left. However, Encinillas Altas, although very reduced in extension (about 1 ha.) may illustrate the type of forest that once existed. An imposing canopy of cork oaks and Arbutus unedo rises to 15 m. Erica arborea (3-5 m) and braken (Pteridium aquilinum) (2-3 m high) form thick matorral. Dense lianas (Lonicera, Clematis) hang from tree branches making a remarkable thick vegetation. Soil is covered by 10-15 cm. of decomposing leaves on top of a 20 cm. deep Ao black horizon rich in humified organic matter. High bracken productivity results in local organic matter accumulation that form humus above soil surface reaching sometimes 50 cm high. This thick forest probably recalls the original Doñana forest; wild olive and chaparro may have been excluded due to oceanic influence.

The effects of fires on this type of forest are devastating. The large amount of fuel available makes the fire last longer; and trees are killed or seriously injured, or have been completely burned together with matorral. The large decrease in primary productivity together with soil exposure induces rapid mineralization of organic matter leaving an impoverished sandy soil with little cation exchange capacity and easily subjected to leaching. Forest regeneration becomes difficult and slow. Senescent trees will die out. Younger ones will regenerate or not depending on the species. Strawberry trees are more likely to be killed. Kermes oak will sprout from the base; wild olive will also grow from the base but it is prone to catch fire in the trunk. Cork oak is the most resistent to fire; thanks to its insulating bark that prevents damage to branches and buds thus allowing for rapid recovery.

According to this differential sensitivity to fires an almost complete extinction of strawberry tree might occur. The extinction of Kermes oak and wild olive trees will occur next, even if they are more resistent. Finally, cork oak must be the least affected of them all. This expected number of each species fit neatly with observed tree numbers of these species on Donana.

Let us now comment on the distribution patterns observed in the stabliized sands: for all species, lagoon borders represent a selective location. Vera ecotone is also important for cork oak and wild olive tree.

Lagoon borders. These are areas where water table is near the soil surface, resulting in numerous advantages relative to fires: wet areas and water saturated plants tend to burn more slowly than drier areas. Winter water rising tends to kill perennials around the lagoon leaving a wide grass belt where fire does not spread. Finally, water availability to the tree will help it recover after fire. This is probably the most important factor responsible for tree conservation around lagoons and in fact it affects all species considered.

Vera ecotone. A few wild olive trees and a large number of cork oaks form a savannah type forest along the vera ecotone. This again represents a favorable location in relation to water availability for trees. In fact drainage networks of stabilized sands discharge into the marsh through Vera ecotone; soil water table lies here only 1-2 m below the surface. Although this fact may explain a better tree recovery after fire, their large numbers in the area may have a different origin. Apparently Vera ecotone matorral has been under heavy pressure both from animals (browsers) and man. Game and cattle feed in the marsh and hide into the stablized sands thus crossing the ecotone twice or several times a day. Evidence also exists for some areas of the Vera to have suffered shifting cultivation: in this case, matorral may have been cut leaving trees unaffected. The combination of both processes may have prevented wild fires to reach the Vera with a frequency comparable to other sites within the stabilized sands thus allowing for the much larger tree population that is found today.

11. Conclusion

Present distribution of trees on the stabilized sands of Doñana agrees well with the hypothesis of an original Mediterranean forest dominated by cork oak and repeatedly devasted by fire. Forest regeneration in burnt areas has been prevented by a combination of repeated fires, heavy grazing by herbivores and a marked extension of matorral. To which extent the forest destruction was accelerated by human impact or climatic change cannot be ascertained at the moment. The only reference (VALVERDE, personal communication) is a description of Doñana area circa 1650. At that time the forest no longer was a closed one but rather a savannah type that allowed trees to be counted. Oak trees were more numerous at the time (10 to 20 times more trees than at present) and their population was still reproducing. This will point towards a long term process that is now in its final stage with isolated patches of non reproducing forests that have been reproducing forests that have been termed "Forêt fossile" by QUESEL (1976).

Turning now to the matorral, its regeneration after fire is remarkably fast, its composition being controlled by topography forming a stable type of vegetation comparable to a pseudoclimax.

However the evidence that the Doñana matorral is rather a mixture of at least two different vegetation types: a xeric type of matorral that may have been associated to Juniperus phoenicea forest and contains Thymus mastichina, Lavandula stoechas, Rosmarinus officinalis, and others. A hygrophytic type of matorral associated to the cork oak forest with Phillyrea angustifolia, Myrtus communis, Erica australis, E.arborea Calluna vulgaris, and E.ciliaris on very wet areas. Repeated fires suppressed tree cover letting fast growing and light demanding species to spread over large areas. Under these conditions, Halimium halimifolium and (probably) Cistus salviaefolius, Cistus libanotis, Halimium commutatum may have spread all over the area bringing the present day matorral composition. The fire adapted H.halimifolium is a fast growing species continuously spreading to new areas. Also Cistus salviaefolius, in sheltered condition, Stauracanthus genistoidis in open ground with available water have largely spread. Slow growers belonging to the original matorral types such as Osyris quadrivalvis y O.lancelata or Phillyrea angustifolia are scarce and appear on very locally.

The vegetation of the stabilized sands of Doñana is thus an interesting example of profound changes brought about in a mediterranean forest ecosystem through the action of repeated fire.

ACKNOWLEDGMENTS

A grant from the Spanish MAB Committee is gratefully acknowledged.

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ENVIRONMENTAL DIFFICULTIES IN THE FIGHT AGAINST FOREST FIRES IN SPAIN.1/

Ricardo Vélez 2/

Abstract: The problems arising from the accumulation of fuel and the negative attitude of some sectors of the population, together with the climatological conditions, are giving rise to a serious increase in the losses caused by forest fires. There is a need for a reform in the fire fighting policy, laying greater emphasis on prevention, both directed towards the control of fuel and to a greater public interest in the conservation of the forest.
Key words: Accumulation, fuel, attitude, population.

INTRODUCTION

Spain has a forested area of 26 million hectares, equivalent to 52% of its total geographical area. Of this, 11·8 million hectares correspond to forests of arboreal species, while the remainder is occupied by non-arboreal species. Reforestation projects have been increasing the forested areas by something over one hundred thousand hectares a year, although this figure has dropped in the last few years as a result of economic difficulties.

The Iberian Peninsula shows very marked climatological contrasts: the peripheral belts beside the sea and therefore enjoying its regulating influence on the humidity and temperature do not suffer the rigourous climate borne by the central meseta, where temperature variations have been measured from a maximum of 45ºC in summer to a minimum of -25ºC in winter. One can distinguish two clearly defined climatic zones. The North and North-West have an obviously Atlantic climate (damp and mild), In contrast, the rest is dry, continental in the Centre and temperate through the influence of the sea on the Mediterranean Coast. At all events, one must emphasize the existence of a prolonged hot, dry period, greatly exceeding the seasonal limits of the summer, during which the vegetation is in a suitable condition to burn.

As a general rule, the most important forests occupy especially the mountain areas, although there exist extensive forests, but with very little density, on the plains of the Centre.

This physical environment, clearly favourable for the appearance and spread of fires, is affected by different factors of a social nature which contribute to the fire problem. Among the most outstanding are:

- The accumulation in the underwood of logs and brushwood which were formerly removed to feed fires and ovens in the country areas, the use of which has diminished as a result of the competition of oil-derived fuels.

1/Presented at the Symposium on Environmental Consequences of Fire and Fuel Management in Mediterranean Ecosystems, Palo Alto, Calif. Aug. 1-5, 1977.

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- The absence of the population which formerly lived in the forests, was interested in their conservation, familiar with the terrain, and skilled in the use of implements, who dealt with the fire from its beginning.

- The increase in the number of hikers, campers and tourists, not always used to the environment, and whose negligence is responsible for a considerable number of disasters.

The circumstances mentioned are not of a transient nature, on the contrary, the number of fires shows a tendency to increase which makes it necessary for us to organize ourselves properly to deal with the danger.

The evolution of forest fires and their effects in recent years is shown in the graphs and figures attached:

Figure 1: Number of fires, reforested area, and area of forest burnt.

Figure 2: Typical distribution of the number of fires throughout the year.

Figure 3: Zones and periods of fire risk.

There follows an analysis of the problems mentioned and of the difficulties they present for the defence against forest fires.

1. The problem of accumulation of fuel.

The forest fires start in Spain as a result of human action on the forest fuel in 95% of the cases.

In our country, inhabited for thousands of years, only as a literary conceit can the appearance of the woodlands and their structure be described as natural. It is really the result of the action of Man, who has seized their terrain, eliminated species and taken advantage of the fruits and materials they offered him. Human action, through removal of brushwood, logging and grazing exploitation, has originated a particular structure of the vegetation, relegating the dense forest areas to the mountain massifs, and drastically clearing the woods of the plains to facilitate their exploitation for cattle raising.

The present-day variation in the agricultural economy and the emigration of the rural population is giving rise to profound changes in this structure, which had displayed a certain stability for nearly four centuries.

In the last twenty years the economic activity of Man in many forest areas has become practically non-existent. This results in the accumulation of dead waste, which, in a dry climate, makes the forests highly inflammable. Here lightning can catch and cause damage, as occurred during the summer of 1976, which was very stormy and had an unusual 9·7% of fires caused by lightning, which burnt nearly 20,000 hectares (12% of the area burnt in the year).

In the wake of the lightning, if the absence of Man continued, there would come a new colonization of the ground, and different phases of vegetation would follow one another. However, this absence of Man is not effective. His lack of activity refers only to the reduction in the removal of woody material. Indeed, the presence of Man is increasing with the intensification of the recreative use of the forests. Hikers and hunters roam all the forest, and only a very small number of areas, by reason of their natural inaccessibility or legal limitations, are infrequently visited.

Thus there is a situation of permanent danger, since Man is a constant carrier of fire, which, together with the accumulated small fuel, inevitably leads to fires.

The production of logs in Spain has dropped by more than 60% since 1961. The reasons for this are the depopulation of the forest areas and the scant market for the logs, replaced by other fuels. The fire risk arising from these facts does not affect all forests to the same extent. The existing statistical data show that the frequency of fires in coniferous forests is ten times greater than in hardwood ones. Although these latter produce greater quantities of dead matter, as they are generally found in damper places the decomposition of the waste is much more rapid, a situation which does not occur in pine woods, normally found in dry areas.

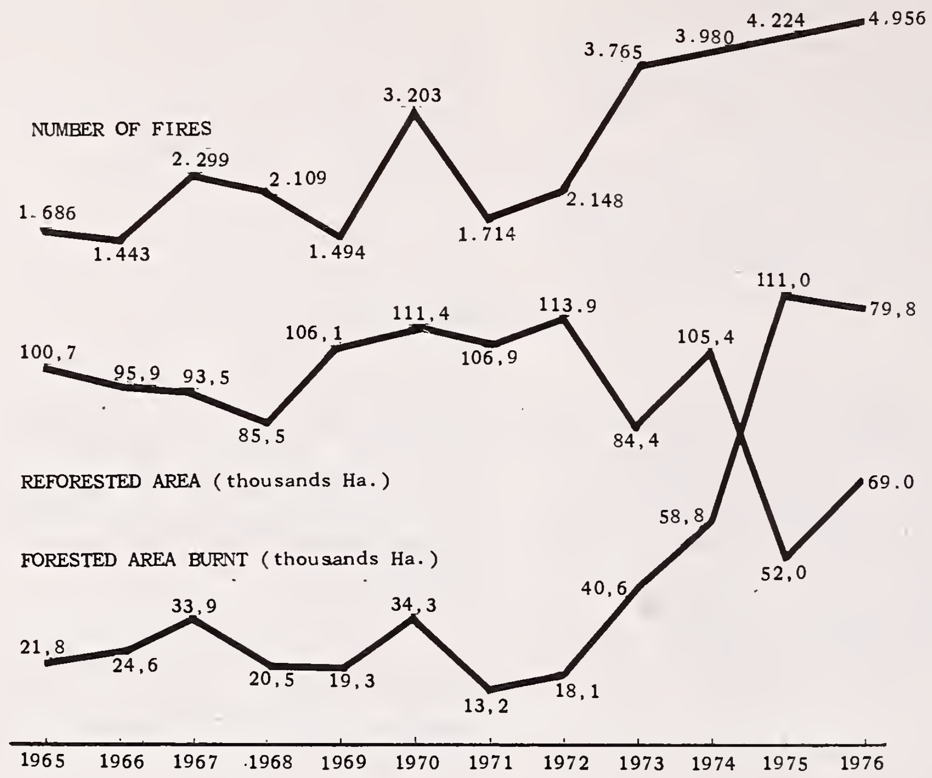

Figure 1--Number of fires, reforested area, and area of forest burnt.

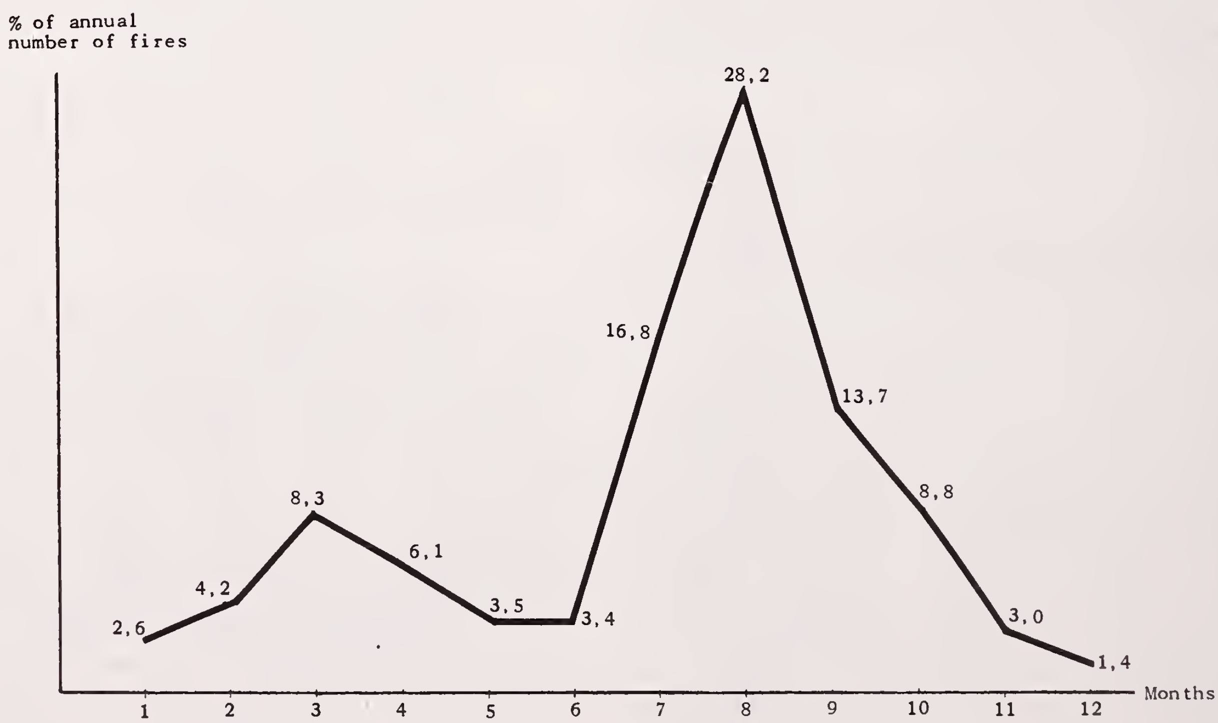

Figure 2--Typical distribution of the number of fires throughout the year.

In this respect it must be pointed out that since 1940 2,200,000 hectares have been planted with conifers in Spain. These young forests are located in all types of terrain, but especially in dry and stony areas, on slopes and peaks where the water runs away or filters through rapidly. The scrub undergrowth is very abundant in some cases; in others the density of the young trees is excessive. Moreover, they are generally continuous stands, forming large perimeters through which the fire can spread unhindered. In the reforested areas the grazing limitations are often prolonged almost indefinitely, for fear that the cattle will damage the trees. In this way, one of the classic systems of reduction, by exploitation,of the small fuel is eliminated, so that these reforested zones become impenetrable areas, in which lightning catches fire easily, and where the extinction work is extremely difficult (in more than 80% of the fires there are habitually difficulties owing to the density of the undergrowth and the excessive proximity of the trees). The amount of fuel in the treeless or pasture zones is also increasing. For example, in all the north of the Peninsula the furze (Ulex europaeus) was a basic product for the agricultural economy. It was used for grazing and for bedding for the cattle, and afterwards as an organic fertilizer mixed with manure. Now the furze remains in the woods, lignifies, and constitutes an ideal fuel to start a fire and spread it rapidly. Being an invading species, it carpets the pinewoods, covers the cultivated land abandoned by the emigrants and even blocks the paths which are not used.

The same phenomenon occurs in the East and South. The largest fire ever known in Spain, (Sierra de Almijara Fire, 1975, 11,762 Ha.), developed precisely in a sparsely planted pinewood, with very thick, high Ulex undergrowth, as a result of the disappearance of the traditional grazing exploitation by herds of goats.

The difficult economic situation affecting other forms of exploitation also results in accumulation of fuel. For example, the pinewoods in resinification, (mainly Pinus pinaster), were regularly cleared of undergrowth to facilitate the production and extraction of the resin. Nowadays, the most difficult of access are relegated to a marginal category owing to the increased costs of extraction. Being sparse stands, the strong sunlight favours the development of the undergrowth. This factor also existed in the above-mentioned Almijara Fire.

The cork-oak groves (Quercus suber) are in a better condition, but the long intervals in the removal of the cork, (9-10 years), leads to their neglect in the interim and the encroachment of the undergrowth.

The holm oak woods, (Quercus ilex), were formerly greatly exploited for their fruit, eaten in the woods by the herds of Iberian pigs. The lack of herdsmen and the high cost of beating the trees to obtain the acorns, in addition to sickness of the herds, has also reduced this exploitation and therefore the elimination of the fuel carried out to facilitate movement in the woods.

2. The problem of the attitude of the population.

It is necessary to distinguish between the attitude of the rural population and that of the city dwellers as regards the woods and fire. To make a generalisation, with all its inherent dangers, it may be said that the urban population in Spain incorrectly considers the woods as public property, whose protection and conservation is a State responsibility, and which the private individual may enjoy without limitations. This attitude gives rise to numerous fires causéd by negligence, such as throwing away lighted cigarrette ends or matches, and lighting fires in dangerous places or periods, principally at weekends. Nevertheless, the number of fires from these causes has lessened gradually over the last ten years from 25% to 15%, as a result of the intensive civic education campaigns carried out.

However the enormous crowds found in summer in the forest areas nearest the most densely populated zones means that the number of fires continues to be high, although the damage they cause is generally slight. This danger is located mainly in the

Mediterranean coastal provinces and in the mountains (Sierra de Guadarrama) near the capital, Madrid. In these areas more than 50% of the fires are due to acts of carelessness by the urban population.

The rural population may be considered as divided into two groups, those who profit from the woods and those who consider that the disadvantages outweigh the advantages. The first group is mainly composed of the inhabitants of the forest zones of the interior, whose woods, both private and State-owned, are administered in such a way that they provide the principal source of employment, both in conservation work and in that of exploitation of the wood and industrial uses. They are, therefore, people who not only do not cause fires, but also make a decisive contribution to their prevention and extinction.

In the second group are included the country people whose means of subsistence is predominantly based on agriculture or cattle-raising. Nevertheless, the farmers are in many areas also forest owners (This is especially common in all the northern provinces: Galicia and Cantábrico) so that they are interested in the conservation of the woods. However, in recent years a problem has arisen from the hunting. On the one hand, the wild animals may damage the crops. On the other, the enormous demand for places to hunt results in a series of tensions which affect the farmer, either as a hunter or because others hunt on his land.

The present laws provide for compensation by the State for crop damage and also control the use of hunting grounds. However the problem continues to exist, and in some cases leads to the burning of woods and treeless zones to frighten off the game or to spoil the hunting for others.

With the cattlemen there exists a long-standing problem arising from the competition between the reforestation carried out by the government and the free-ranging cattle. These difficulties are concentrated in the northern provinces, since the reforestation in the rest of the country has been carried out in general in useless and abandoned areas, retaining the traditional pastures in close connection with the wooded areas.

In the northern provinces mentioned, the reforestation has occupied lands used by the community as a whole for grazing. This has caused profound changes in the way of life of the local people who, in many cases, have reacted violently, with repeated fires. It must be taken into account that in these areas the population is widely scattered in small villages and so the fire problem is general.

These problems are the basic factors in intentional fires; the number has increased enormously in recent years, exceeding 30% of the total, but this increase is believed to be due to other factors, probably to action by terrorist groups who take advantage of the ill-feeling among the country people to provoke greater social unrest.

The traditional burning of grazing and agricultural waste to prepare the ground now causes no more than 7% of the fires, thanks to the vigilance exercised and the campaigns directed at the farmers to induce them to take due care. Attached there is a table of the causes of fires, according to the degree of intention.(Table 1)

3. The problem of the fire-fighting policy.

In the face of these problems of accumulation of fuel and negligent or unfavourable attitudes on the part of the public towards the woods, there exists a permanent defensive activity, which began in a systematic way in 1956, with the creation of the Forest Fire Service.

Since that time, three main lines of action have been followed. The first is directed toward the reduction of fuel, by means of clearing and the opening of fuel breaks, which forms part of the general conservation work in the forests.

The second is directed towards the arousing of awareness of the fire risk and the importance of the property they threaten, by means of educational

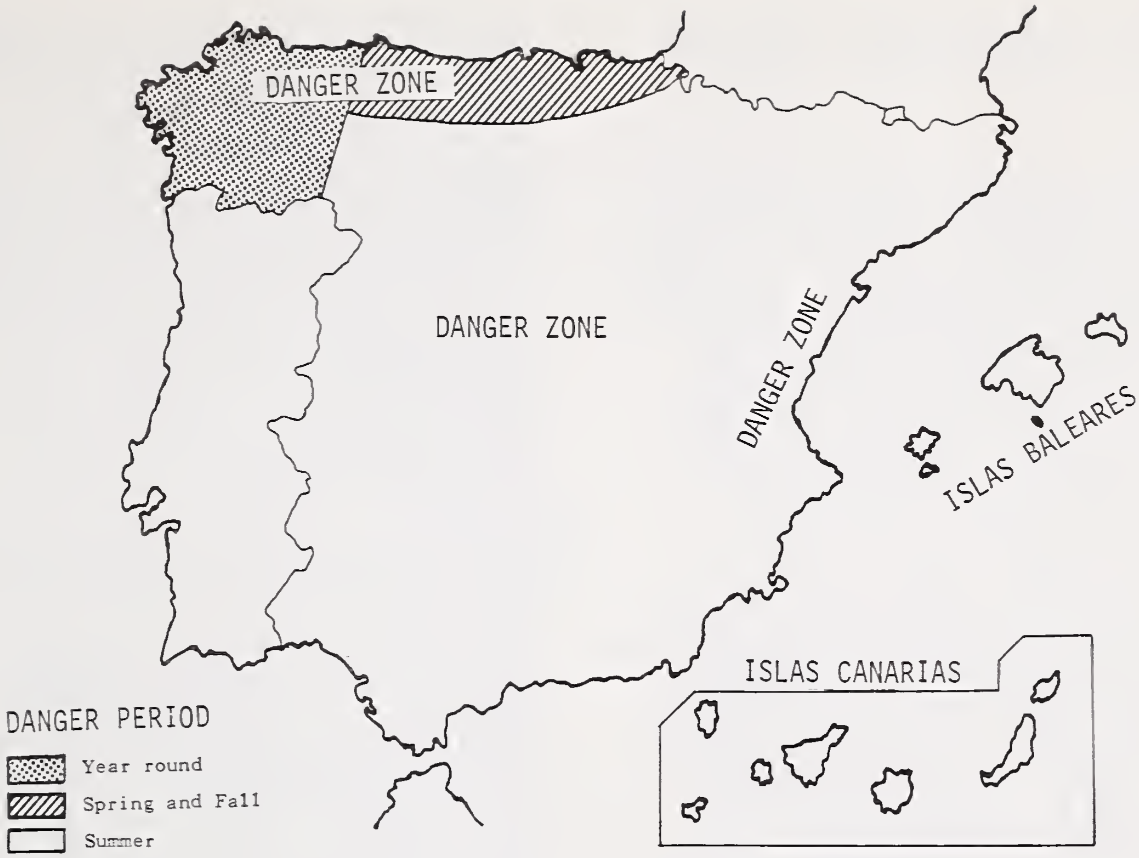

Figure 3--Zones of periods of fire risks.

Table 1--
Classification of fires by causes according to the degree of intent.

Type	Main cause	Motives	Zones of the country
Natural	Lighting	Drought, abundant undergrowth and small fuel in general.	General.
Agricultural	Farmers	Burning of agricultural waste or pastures, usually unauthorized.	Galicia and Cantábrico.
Negligence	Citizens	Ignorance of the danger. Abundance of small fuel.	Cataluña, Eaśt, Andalucía Guadarrama.
International	Farmers	Resentment towards reforestation. Ignorance of benifits of woods. Resentment towards hunting preserves and their damage.	General.
Organized	Unknown	Provocation of social unrest.	General.

Table 2-- Losses through fires

Year	Number of fires	AREA AFFECTED IN HECTARES			Losses in primary products (millions pts)	Losses in protective values (millions pts)	Losses in recreational values (millions pts)	Social-economic repercussion (millions pts)	Total losses (millions pts)
		Forested	Treeless	Total					
1961	1.630	34.506	12.195	46.701	928	167	180	228	1.503
1962	2.022	23.911	31.571	55.482	598	205	193	109	1.105
1963	1.302	13.279	9.400	22.679	311	59	177	76	623
1964	1.645	17.671	13.727	31.398	372	159	173	214	918
1965	1.686	21.777	16.241	38.018	412	216	164	219	1.911
1966	1.443	24.644	24.710	49.354	446	314	168	218	1.146
1967	2.299	33.930	42.645	76.575	575	417	174	267	1.433
1968	2.109	20.547	36.081	56.628	549	254	169	232	1.244
1969	1.454	19.296	34.423	53.719	484	237	208	211	1.140
1970	3.203	34.330	52.994	87.324	764	480	248	448	1.940
1971	1.714	13.194	21.751	34.945	334	167	253	237	991
1972	2.148	18.048	39.235	57.283	559	201	267	548	1.575
1973	3.765	40.559	54.698	95.257	1.118	503	341	730	2.692
1974	3.980	58.789	81.422	140.211	1.992	1.689	1.126	4.894	9.701
1975	4.242	111.091	76.223	187.314	4.121	2.409	2.001	9.445	17.976
AVERAGE	2.316	32.371	36.487	68.858	904	501	389	1.205	3.000

and propaganda campaigns directed at the different social groups: children and adults, town and country people, tourists etc.

The third is directed towards the creation of a powerful and efficient extinction system, by means of a detection network covering the whole forest area, a system to determine the degree of risk, a network of forest tracks and water points, extinction groups equipped with the appropriate implements and vehicles, a depot of pumping engines in every province and a fleet of extinction planes able to operate over the entire country.

However, after twenty years of operation, the development in the three fields can be seen to be unequal. The extinction system has developed to a notable extent; the educational campaigns also have caught the attention of the public to a high degree. However the work of fuel reduction has not advanced sufficiently. The woods which are private property (7,800,000 Ha.) are practically abandoned, and in the State-administered woods, (4,000,000 Ha.), the work is carried out sporadically, when there are, for example, credits available for the fight against unemployment.

At the same time, the arson problem is growing, for various reasons, without there existing an intense police activity to control it.

Table 2 gives data referring to the number of fires, area affected and losses in forestry products and environmental benefits since 1961.

4. Conclusions.

From these observations and data it has been possible to draw the following conclusions:

- The structural causes of the forest fires, with reference to the accumulation of fuel in the woods, their profitability, and the public attitude towards them become more serious as time passes, while the preventive measures taken are insufficient to control the increasing risks.

- The extinction work has managed to reduce losses, so that these have increased in a lesser proportion than the number of fires; nevertheless, in recent years, owing to the insufficient preventive measures, the extinction resources are overwhelmed.

- The increasing cost of extinction reduces the funds available for investment in preventive work. Moreover, the losses through fire are creating a negative atmosphere for investment in reforestation. Thus the results of the firefighting activities give rise to greater difficulties for the defence of the woods and the forestry economy.

- It is becoming essential to consider fire prevention as of priority importance with forestry policy. To this end it is necessary to study and apply political and technical measures to permit the control of fuel in forest areas and to increase public interest in the conservation of the forests.

Together with the traditional educational and propaganda activity, it is necessary to use techniques which reduce the cost of eliminating the fuel, taking into account the experience available of grazing in the woods and controlled burning.

However, the application of these techniques in Spain requires a study in depth, owing to the resistence and prejudices existing in wide sectors towards the use of fire, and to make compatible the grazing and forestry exploitation. These difficulties are greatest precisely in the areas with the most serious forest fire problems, for example Galicia and Cantábrico (North of Spain). In other regions, on the other hand, (Central Meseta, Iberian System), the use of grazing in the woods dates from way back, both in conifer forests and in hardwood areas and treeless zones, and here the fire risk is less.

It is moreover necessary to develop new systems of splitting up the fuel, which improve on the traditional fuel breaks of bare ground, without altering the landscape and in combination with the cattle-raising use.

Finally, there is a need for a forestry policy designed to improve the profitability of the woods, and

to encourage the participation of the population in the task of conservation. The benefits produced by the woods for the whole community (protection of soil, hydrological control, purification of the air, recreation etc.) make it essential that it should be the public who take responsibility for defending them. The example set by certain areas of the country, (provinces of the Iberian System) in which the public is aware of the need to defend the woods and moreover knows how to do so, in close collaboration with the Forestry Services, must be extended to other regions to prevent their deforestation, which is progressing at an alarming rate in recent years.

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FIRE AND VEGETATION

IN

NORTH AFRICA[1/]

by

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Abstract : The main vegetation types of the Mediterranean zone of North Africa and their broad ecology are listed with their respective acreage. The occurence of wildfires in the various countries of the area is analysed. The effects of wildfires on three main vegetation sequences are explained and general conclusions are drawn from these three examples ; i.e. fire intensity and frequence is probably the main causative factor of forest vegetation dynamics in North Africa, however the action of wildfires can hardly be separated from two other main factors : wood cutting and overbrowsing which act in conjunction with wild fires in the diversification of natural vegetation.

Key words : Fire, vegetation, vegetation dynamics, vegetation sequences, North Africa.

INTRODUCTION

North Africa is understood in this paper as the portion of the African continent, North of the Sahara and between the Atlantic Ocean and the Red Sea. This area includes the following countries, from west to east : Morocco, Algeria, Tunisia, Libya, and Egypt.

These countries cover the following surfaces of forestland, bushland and shrubland which are subject to periodical wildfires.[3/]

However, all vegetation types are not affected by fire ; only the forests, degraded forests (and locally stubbles) are subject to burning.

These forests and shrublands are almost entirely located in the semi-arid to humid zones with an average annual rainfall above 350-400 mm.

Therefore, if we eliminate the huge areas of arid and desert zones, we have the following proportions of forest and shrubland and afforestation rates (table n°1).

Table n°2 gives a clearer picture of the importance of forest and shrubland in the landscapes of the typical Mediterranean zones of North Africa. Forest and derived shrubland (maquis and garrigue) occupy 40 % of the land while about 50 % is under cultivation.

[1/]Paper presented at the Symposium on Environmental consequences of Fire and Fuel Management in Mediterranean Ecosystems, Palo Alto, California, Aug. 1-5 1977.

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[3/]Forest = over 100 trees, over 5 m high per hectare
Bushland = less than 100 trees per hectare + shrubs
Shrubland = shrubs only, no trees.

Table n°1

	Morocco	Algeria	Tunisia	Libya	Egypt	Total
Surfaces of Forest and Shrubland (10^3 ha)	4,116	2,972	1,105	215	2	8,412
Total surface of the country (10^3 ha)	44,500	238,000	16,500	176,000	100,000	575,000
Afforestation rate%	9.2	1.2	7.0	0.1	0.02	-

Table n°2

	Morocco	Algeria	Tunisia	Lybia	Egypt	Total
Area of semi arid to humid climates 10^3 ha	10,000	9,000	2,000	600	-	21,600
%	22	3.8	12	0.2	-	3.8
Afforestation rate in the semi arid-humid zones (%)	41	33	55	35	-	40

VEGETATION TYPES

Physiognomy and structure

Vegetation types are numerous and closely linked to climatic factors (rainfall, winter temperature mainly) as shown by Emberger as early as 1939. From the physiognomic point of wiew natural vegetation may be classified as follows :

Forest : no less than 100 trees of no less than 5 m of height per hectare
Bushland : less than 100 trees per hectares usually mixed with shrubs of various size
Shrubland : mixed shrubs of various size (a shrub being defined as a multistemmed ligneous plant, usually less than 5 m in height)
The term shrubland includes the notions
. of Maquis : dense, tall evergreen shrubland under rather favourable water regime usually on more or less acid soils and in higher rainfall areas
. of Garrigue : low, open evergreen shrubland in very dry habitats and soils often calcareous and shallow
. of Matorral which covers both notions of Maquis and Garrigue
. of Chaparral which is the american synonym for Matorral.

Very degraded forms of garrigues usually dominated by undershrubs of the *Cistaceae* and *Labiateae* families bear various local names : Tomillares in Spain, Phrygana in Greece, Batha in Israel etc.

The above physiognomic types are found in almost all the semi arid to humid Mediterranean zone of North Africa. They constitute various dynamic stages which remain more or less equivalent through the various vegetation sequences derived from primeval forests. Primeval vegetation types are everywhere forest ; however it is not evident that, due to soil degradation, the climax is everywhere a forest at the present day. In all cases the dynamic succession may be schematically represented as follows :

Primeval forest
↓
Open forest
↓
Bushland
↓
Shrubland
↓
Degraded shrubland

In all the sequences of this dynamic succession fire plays some role and often the most important one, as will be shown further on.

Bioclimatology and dynamic sequences

Using two simple criteria: average annual rainfall "R" and mean minimum temperature of the coldest month "m", it is possible

to draw a bioclimatic framework fitting the North african vegetation.

These two criteria have been selected because they best match the phytogeographical and phytosociological facts pertaining to vegetation distribution (chorology).

This is due to the fact that these two criteria are correlated with other climatic parameters for instance :

Average annual rainfall is strongly correlated with

- number of rainy days
- lenghts of the rainy/dry seasons
- inversely correlated with potential evapotranspiration
- rainfall increases with elevation along a gradient of 5-10 % per 100 m of difference of level

Mean minimum temperature of the coldest month (January) is correlated with

- lenght and intensity of frost
- altitude : decrease in altitude is of 0.5°C per 100 m
- continentality

These correlations have been studied by Le Houérou (1969, 1975,1977) and others and the correlations coefficients published. This method is derived from Emberger's classification ; we have thus :

. According to precipitations

A - 1 200 mm	R <	medit. perhumid	bioclimate
B - 800 <	R<1 200	" humid	"
C - 600 <	R < 800	" subhumid	"
D - 400 <	R < 600	" semi arid	"
E - 100 <	R < 400	" arid	"
F - 20 <	R < 100	" desert	"

. According to mean minimum temperatures of January

a - $9°C < m$	very warm	winters	no frost at ground level
b - $7 < m < 9$	warm	"	no fr. under shelter
c - $5 < m < 7$	mild	"	1-10 days of light frost
d - $3 < m < 5$	temperate	"	10-20 days of light frost
e - $1 < m < 3$	cool	"	20-30 days of light frost
f - $-2 < m < 1$	cold	"	30-60 days of light frost
g - $-5 < m < -2$	very cold	"	60-120 days of serious frost
h - $m < -5$	high mountains		over 120 days of severe frost

We have thus theoretically 6 x 8 = 48 combinations or types and subtypes of Mediterranean bioclimates; in fact there are less numerous since some combinations never occur for various reasons : Table n°3

		A	B	C	D	E	F
	m \ R	1200	800-1 200	600-800	400-600	100-400	20-100
a	9	+	+	+	+	+	+
b	7-9	+	+	+	+	+	+
c	5-7	+	+	+	+	+	+
d	3-5	+	+	+	+	+	+
e	1-3	+	+	+	+	+	+
f	-2 - 1	+	+	+	+	+	-
g	-2 to -5	+	+	+	+	(+)	-
h	-5	(+)	(+)	+	+	(+)	-

+ = Existing combination
(+) = Doubtful combination
- = Non existing combination

According to this bioclimatic classification we have the following types of forest, bushland and shrubland dynamic sequences or "series" (main dominant species) :

1 - Sequence of Abies	Per humid and humid with cold and very cold winters
Abies pinsapo	
" maroccana	Ag, Af
" numidica	Bg, Bf
2 -Sequence of Pinus pinaster subsp mesogeensis	
Pinus pinaster mesogeensis	Per humid and humid warm to cold Aa, Ab, Ac, Af, Ag Ba, Bb, Bc, Bf, Bg
3 - Sequence of deciduous oaks	Per humid and humid warm to cold
Quercus faginea	Aa, Ab, Ac, Ad, Ae, Af
Q. afares	Ba, Bb, Bc, Bd, Be, Bf
Q. toza (very restricted small patches in Northern Morocco only)	
4 - Sequence of evergreen oaks	
Quercus suber	Humid to sub humid warm to cold Ba, Bb, Bc, Bd, Be, Bf Ca, Cb, Cc, Cd, Ce, Cf (Db, Dc, Dd)
Quercus ilex	Semi arid to humid temperate to cold Bd, Be, Bf Cd, Ce, Cf Dd, De, Df
Quercus coccifera	Semi arid to humid very warm to temperate Ba, Bb, Bc, Bd Ca, Cb, Cc, Cd Da, Db, Dc, Dd

Q. calliprinos (E. Lybia only)	Sub humid and Semi arid very warm to temperate Cb, Cc, Cd Db, Dc, Dd
5- Sequence of Pinus laricio (very limited, Algeria)	Sub humid to humid cold to very cold Bf, Bg Cf, Cg
6- Sequence of Cedrus libanotica subsp. atlantica	Sub humid to humid cold to very cold (Bf), Bg (Cf), Cg (Df , Dg)
7- Sequence of Pinus halepensis	Sub humid to arid warm to cold Cb, Cc, Cd, Ce, Cf Db, Dc, Dd, De, Df Eb, Ec, Ed, Ec, Ef
8- Sequence of Tetraclinis articulata	Arid to Semi arid warm to temperate Da, Db, Dc, Dd Ea, Eb, Ec, Ea
9- Sequence of Juniperus thurifera	Arid to Sub-humid very cold and high mountain Cg, Ch Dg, Dh Eg, Eh
10- Sequence of Juniperus phoenicea	Arid to Semi arid very warm to cold Da, Db, Dc, Dd, De, Df Ea, Eb, Ec, Ed, Ec, Ef
11- Sequence of Argania spinosa (SW Morocco only)	Arid and Semi arid very warm to mild Da, Db, Dc, (Dd) Ea, Eb, Ec, (Ed)
12- Sequence of Olea europaea-Ceratonia siliqua	Semi-arid to humid very warm to temperate Ba, Bb, Bc, Bd Ca, Cb, Cc, Cd Da, Db, Dc, Dd
13- Series of cushion-like xerophytes (High mountains) Erinacea anthyllis Bupleurum Spinosum etc...	Sub humid to arid High mountains Ch, Dh, (Eh)

Geographically, these vegetation sequences are distributed as follows and cover approximately the acreage shown in table n°4.

Table n°4

Acreage of the various sequences by country (in 10^3 hectares)

Domin. Species	Morocco	Algeria	Tunisia	Libya	Total
Abies	5.5	1.0	-	-	6.5
Pinus laricio	-	0.1	-	-	0.1
Decidious oaks (Q. faginea mainly)	24.0	67.0	25.0	-	116.0
Cedrus	115.0	30.0	-	-	145.0
Juniperus thurifera	31.0	1.0	-	-	32.0
Pinus pinaster	15.0	12.0	2.0	-	29.0
Quercus suber	367.0	440.0	127.0	-	934.0
Quercus ilex	1345.0	676.0	83.0	-	2004.0
Quercus coccifera	-	41.0	3.0	-	44.0
Quercus calliprinos	-	-	-	10.0	10.0
Pinus halepensis	65.0	843.0	340.0	5.0	1253.0
Cupressus	8.5	0.1	0.1	0.5	9.2
Tetraclinis	740.0	30.0	30.0	-	931.0
Olea - Ceratonia	500.0	100.0	70.0	50.0	820.0
Juniperus phoenicea	200.0	600.0	425.0	150.0	1375.0
Argania sidoroxylon	700.0	-	-	-	700.0
TOTAL	4,1160	2,972.2	1,105.1	215.5	8,408.8

Of course, plant communities are much more numerous ; each one of the vegetation sequences mentioned above are composed of several plant associations owing to variations in botanical composition resulting from climatic and edaphic conditions and of vegetation structure

resulting mainly from the type and intensity of land use.

FIRE

Wild fires burn annually an average of some 50 000 hectares of forest and shrubland. If fire occurence were equally distributed each piece of forest of shrubland would burn every 170 years.

In fact, it is not so since huge surfaces of shrubland are too degraded and/or too open to permit fire transmissions and therefore never burn over sizeable surfaces.

Less than 50 % of the forest and shrublands of North Africa are dense enough to permit burning i.e. some 4 million hectares burn in average once every 80 years, this is in agreement with the empiric statement made by several geobotanists and foresters that there is probably nowhere in North Africa any piece of forest which has not been burnt at least once in a century.

The following data are computed from official statistics.

Table n°5

Fire occurence

	Aver. number of fires per year	Aver. area burnt per year (10^3 ha)	Area of average fire(ha)	% of forest burnt p/y
Algeria	300	40.0	133	1.3
Tunisia	50	6.0	120	0.5
Morocco	60	2.5	42	0.05

The reason for the large differences from country to country in the percentage of forest burnt every year is not well understood. It is probably due to differences in attitude of the local populations, rather than to other factors such as climate, management etc...

There is a wide variation in surface burnt every year ; in Algeria, for instance, this surface varied from 1,600 ha in 1929 to 169,000 ha in 1881, i.e., a variation factor of 1 to 10.

Wild fires occur in daytime, mainly in summer from july to september (55-65 %), i.e., in the dry season.

The reported causes are the following (Boudy, 1948) :

	Algeria	Tunisia
Carelesness (burning for pasture)	40-50%	55-60
Malignity	20-25	38-40
Unknown	30-35	10-15

Unlike other areas in the world it seems that natural fires originated by lightnings are almost negligible.

The highest fire occurence is in rainfall area where there is more fuel. The most sensitive are the Aleppo pine forests and the degraded maquis of *Quercus suber* and *Q. faginea* with a high proportion of cistaceae (*Cistus sp. plur. Halimium sp. pl. etc...*) which are extremely prone to burning. These species are true pyrophytes i.e. their self regeneration is greatly increased by fire. Homogeneous populations of *Cistus (C. monspeliensis, C. ladaniferus, C. salviifolius)* cover huge areas, they all result from repeated burning.

Some areas, especially in NE Algeria between Skikda, Annaba and Guelma are burnt at least every 10 years ; fires are much less frequent in western Algeria.

FIRE AND VEGETATION

The present day vegetation in North Africa is the result of a long history where man has played an essential role through :

- woodcutting (Timber, firewood, distillation, charcoal)
- burning (for pasture, for clearing, for cultivation)
- grazing and browsing (especially in the dry season)

These three dynamic factors can hardly be separated as they almost always act in conjunction.

4.1 - The *Quercus faginea/Q. suber* sequence

Q. faginea forests occur in high rainfall areas (over 800 mm of precipitation) on more or less acidic soils. *Q. faginea* is a tall deciduous tree (10-20 m) very similar in shape and leaves to the english oak (*Q. robur*).

In well developed forests, probably close to the primeval type, the dominant species are

Q. faginea	*Hedera helix*
Cytisus triflorus	*Viburnum tinus*
Russcus hypophyllum	*Tamus communis*

Q. faginea is very sensitive to burning, almost all trees are killed when a fire of some intensity occurs. Therefore *Q. faginea* forest are restricted in acreage (10%) in respect to the area they could ecologically cover (100 000 hectares and over one million hectares, respectively).

Repetitive burning with a frequency inferior to 40-50 years leads to the replacement of *Q. faginea* by a fire resistant oak : *Q. suber*

which is a passive pyrophyte almost indifferent to burning. Quezel (1956) stated that *Q. suber* is not a climax or primeval forest type but a stage of the *Q. faginea* sequence induced by burning, and I, for one, fully endorse this statement supported by many of my field observations in Tunisia, Algeria and Morocco.

The *Q. suber* stage is characterized by the following dominant species

Q. suber	*Phillyrea media*
Erica arborea	*Calycotome villosa*
Myrtus communis	*Arbutus unedo*
Daphne gnidium	*Cistus monspeliensis*
Lavandula staechas	" *salviifolius*

which may be considered as pyrophytes. When the *Q. suber* forest or bushland itself is degraded by recurrent burning, cutting and browsing it gives way to a maquis of *Erica arborea* and *Arbutus unedo* with the following dominant species :

Erica arborea	*Arbutus unedo*
Caly cotome villosa	*Daphne gnidium*
Myrtus communis	*Phillyrea media*
Lavandula staechas	*Cistus monspeliensis*
Halimium halimifolium	" *albidus*
	" *salviifolius*

in a further stage only the *cistaceae* remain. When those are in turn eliminated eroded ground covered mainly by annuals or geophytes is the last stage before bare land.

The dynamic sequence of *Q. faginea* may be summarized as follows :

1 - Undisturbed forest of *Q. faginea*

Burning ↓

2 - Forest bushland of *Q. suber*

Burning ↓

3'- Tall shrubland (Maquis) of *Erica arborea*, *Arbutus unedo*

Burning + Erosion ↓

4 - Short open shrubland of *Cistus monspeliensis*, " *albidus*, *Halimium halimifolium*

Burning + Erosion ↓

5 - Erme or sward of *Helianthemum tuberaria*, " *guttatum*, *Asphodelus microcarpus*, *Preridium aquilinum*

4.2 The *Quercus ilex/Pinus halepensis* sequence

This sequence occurs in less humid conditions than the *Q. faginea/Q. suber* series, i.e. in the semi arid to sub humid bioclimatic zone with precipitation ranging from 400 to 800 mm.

Unlike in the *Q. faginea/Q. suber* sequence, soils are usually calcareous.

The primeval forest is dominated by Holm oak *Quercus ilex* an evergreen oak 10-15 m high.

with the following main species

Olea europaea	*Pistacia terebinthus*
Juniperus oxycedrus	*Pistacia lentiscus*
Rubia peregrina	*Lonicera implexa*
Asparagus acutifolius	*Ruscus aculeatus*
Phillyrea angustifolia	*Rhamnus lycioides*

Burning, cutting and browsing (Holm oak is an excellent browse) give way to a mixed forest or bushland of *Q. ilex* ans *Pinus halepensis* where *Q. ilex* is reduced to shrub size and kept so by browsing and cutting and where *P. halepensis* constitutes the higher tree stratum. *P. halepensis* is favoured by burning which helps in the dissimination of seeds and the growth of its hellophilous seedlings. Most of the present day Aleppo pine forests and bushland belong to this stage whereas the *Q. ilex* forests are extremely rare.

Repetitive burnings of the Aleppo pine forest gives way to shrublands dominated by

Rosmarinus officinalis	*Ampelodesmos maritanicum*
Juniperus oxycedrus	*Phillyrea media*
" *phoenicea*	*Rhamnus lycioides*
Pistacia lentiscus	*Olea europaea*
Genista sp. pl.	*Erica multiflora*
Ulex sp. pl.	*Cistus villosus*
Coronilla sp. pl.	" *libanotis*
Globularia alypum	" *salviifolius*
Thymus sp. pl.	*Helianthemum sp. pl.*
	Fumana sp.pl.

The last stage before bare ground is dominated by a low, open vegetation of undershrubs dominated by *cistaceae* and *Labiateae* such as

Cistus villosus	*Thymus sp. pl.*
" *libanotis*	*Satureja sp. pl.*
Helianthemum sp. pl.	*Lavandula sp. pl.*
Fumana sp. pl.	*Teucrium sp. pl.*

The *Q. ilex/Pinus halepensis* sequence may be summarized as follows :

1 - Primeval forest of *Quercus ilex*

cutting, burning

2 - Forest and bushland of *Q. ilex Pinus halepensis*

cutting, browsing, burning

3 - Shrubland of *Rosmarinus officinalis*

cutting, browsing, burning

4 - Low, open shrubland of *Cistus/Thymus*

4.3 - The *Pinus halepensis/Juniperus phoenicea* sequence

This sequence is restricted to the arid zone between 200 and 400 mm of average annual precipitation on various soils and geological substrata, usually of a calcareous nature.

Climate is too arid for holm oak.

Relatively undisturbed forests are made of :

Pinus halepensis *Juniperus phoenicea*
Rosmarinus officinalis *Rhamnus lycioides*
Olea europaea *Cistus libanotis*
Stipa tenacissima

Frequent burning and cutting give way to shrubland of

Juniperus phoenicea *Rosmarinus officinalis*
Cistus libanotis
Stipa tenacissima

This stage is very stable and little affected by burning (too open) overcutting and overbrowsing lead to a steppe of *Stipa tenacissima-Artemisia herba alba* which in turn gives way to an *Artemisia* steppe by overexploitation of esparto.

This sequence may be summarized in the following way :

1 - Primeval forest of *Pinus halepensis*

cutting, burning

2 - Mixed bushland of *Pinus halepensis/Juniperus phoenicea*

burning, cutting

3 - Shrubland of *Juniperus phoenicea Rosmarinus officinalis*

cutting

4 - Mixed steppe of *Rosmarinus Stipa tenacissima*

Esparto exploitation

5 - Steppe of *Stipa/Artemisia herba alba*

Esparto exploitation

6 - Steppe of *Artemisia herba alba* (silty soils) or *Artemisia campestris* (sandy soils)

CONCLUSIONS

Three vegetation sequences have been examined above :

. one in the humid bioclimate (*Quercus faginea/Q. suber)*

. one in the semi arid to sub humid bioclimate *(Quercus ilex/Pinus halepensis)*

. one in the arid bioclimate (*P. halepensis/Juniperus phoenicea)*

The first sequence shows that, as a result of burning mainly, a forest of fire-sensitive deciduous oak (*Q. faginea)* is progressively replaced by a fire resistant evergreen oak *(Q. suber)* which in turn gives way to typical pyrophytic shrub vegetation. The main factors of vegetation dynamics is the intensity and frequency of wildfires. When fires occur at intervals of 20 years or less, there is no tree regeneration and the vegetation is a shrubland of typical pyrophytes such as the *Cistus* species which have a short life cycle and are able to reseed after 2-3 years whereas cork oak would hardly produce any seed before the age of 20 years.

The second sequence shows that recurrent burning replaces a mildly sensitive evergreen hardwood (*Q. ilex)* by a coniferous whose regeneration is favoured by periodical fires. But again, when fire occurs more than once in twenty years, the pyrophytic tree itself is replaced by pyrophytic shrubs having a shorter life-cycle.

The third sequence is only initiated by fire ; then, once the aleppo pine has been eliminated there is not enough fuel left for fire to play a significant role in the vegetation dynamics.

Other similar sequences could have been examined for instance :

Cedrus libanotica/Juniperus oxycedrus
Quercus coccifera/Tetraclinis articulata etc

They all develop under the same mechanism in which fire plays a major role, especially in the early stages of the sequence, then cutting and browsing act in conjunction with fire to lead from forest to bushland, shrubland and badlands

It is however evident that wild fires could be avoided by better management using in particular the techniques of prescribed burning, which have been shown to be perfectly feasible in the Mediterranean (Liaccos, 1973), However foresters and managers in the Mediterranean basin in general and in North Africa in particular, are extremely sensitive to fire hazards and do not seem to be ready, as yet, to accept prescribed burning. An important task of information and training still remains to be done in order to be able to reduce the desastrous effect of wildfires on forest production in North Africa.

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FIRE PROBLEMS AND PROGRESS IN CHILE[1]

J. H. Dieterich[2]

Abstract: Fire problems in Chile fall into two categories: Those associated with the effects of fire on the various cover types that are being exposed to fire; and those associated with the administration of the fire control program. Information is lacking on the response of various species and plant communities to wildfires, and information is needed on the use of fire as a management tool. Progress in fire control in Chile has been substantial during the past 15 years. Detection and prevention have improved, and the area burned and average size fire have been steadily reduced. Modern equipment and improved training of fire crews have been important contributors to this progress.

Key words: fire effects, fire suppression, prescribed fire, fire ecology

INTRODUCTION

In October 1973, I returned from Chile following a 2-year assignment with the Peace Corps. Stationed in Santiago, I served as a staff specialist to the Fire Protection Division of the National Forestry Corporation, helping with a variety of tasks relating to fire prevention, fire suppression and training. My training and fire suppression duties took me to nearly all regions where fires were a problem, and while I was not specifically assigned the task of describing fire ecology of the various species, my background in fire research prompted a rather extensive volume of observations of fuels, vegetative types and fire effects.

My presentation here will not deal to any large extent with the fire ecology of the many species influenced by fire in Chile. I don't have this knowledge at hand, nor do I believe that anyone else has made any extensive studies of the effects of fire on many of the native or introduced species affected by fire in Chile. Instead, I would like to make some very general observations concerning the effects of fire on certain vegetative types; to review what few references I was able to locate; and, finally, to introduce some of the problems and progress in fire control and fire management in Chile.

Chile is a country of diverse climatic and vegetative types. Perhaps no other country of its size has such a variety of natural resources, extending from the desert region in the North where rainfall averages less than .01 inch per year, to the Chilean holdings in the Antarctic in the South; from the more than 4,000 miles of coast line on the West to the crest of the Andes on the East with elevations rising to nearly 20,000 feet. Chile extends North and South through nearly 38° latitude--a distance roughly equivalent to the expanse between Ketchikan, Alaska and Mexico City.

The country may be roughly divided into three regions: the northern one-third which is primarily desert; the central one-third where the population centers are located, and crops are produced by irrigation and natural rainfall; and the lower one-third which is made up of three large island provinces extending from the city of Puerto Montt at the southern tip of the Pan American Highway, down to Cape Horn at the tip of South America.

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In the northern one-third, vegetation is so sparse that fires are not a problem. The central region has a truly Mediterranean-type climate where native and introduced plants develop under the influence of mild temperatures, and a rainfall regime that averages about 300 mm per year. In the southern portion of this central region, the rainfall amounts increase rapidly to nearly 10 times what is experienced to the north. In the entire central region, the dry season extends from November to March, and fires may occur during any of these months.

The lower third of the country, because of its proximity to the ocean, experiences relatively mild temperatures and heavy rainfall--in excess of 2,500 mm annually. On the southern tip of Chile, centered around the island of Tierra del Fuego, rainfall is heavy, and the vegetation reflects the severity of the climate--damp and windy but generally not severely cold. Fires do occur in this region, but they are relatively rare.

FIRE ECOLOGY

Chile, like many of the developing nations, has not been able to afford the luxury of having sufficient plant ecologists to study the response to fire of various of their native and introduced plant species. Although conditions are changing, trained individuals have generally not been available to develop this missing information.

An appropriate example of the need for this missing information concerns the native Alerce (*Fitzroya cupressoides* (Mol.) Johnson). The existence of this species, occurring mainly in southern Chile between latitudes 39° 50' to 43° 30', is threatened by both cultural practices and ecological factors. The Alerce, for centuries, has been utilized for shipbuilding and domestic construction; in the 17th Century, wood from the Alerce tree was one of the most important products of the Chilean colony. The boards were so valuable that they were used as a medium of exchange and as a standard against which the value of other items could be determined (Veblen 1976). Veblen (1976) also suggests that the Alerce had actually been declining in southern Chile for centuries before the arrival of the Spaniards in the 16th Century--probably as a result of a trend toward a warmer, less humid climate. He also suggests that Alerce may, in fact, be a true "relict" in the sense that it may not be able to regenerate indefinitely under the present climatic trend toward a warmer drier site. If this is true, the Alerce may be on its way out, regardless of the efforts put forth to protect and preserve it.

Evidence indicates conclusively that Alerce regenerates rather poorly following cutting, and, on a large part of the area, the problems of regeneration have been closely associated with livestock grazing and the indiscriminate use of fire (Veblen 1976). Wildfires are not common in uncut mature Alerce stands, but large destructive fires have occurred during dry years. The species apparently does not sprout from the stump but has been observed to develop from seed following fire (Wilhelm 1968). However, recurrent fires, set to further clear the land, almost totally eradicate any seedlings that develop.

If fire has a place in the ecology of Alerce, it appears to be in the initial conversion process to stimulate seedling establishment following cutting. Continued use of fire does not appear to be an acceptable practice in the management of this important species.

The Monterey pine (*Pinus radiata* D. Don) is recognized as perhaps the most important conifer introduced to the southern hemisphere (Roy 1966). Known locally in Chile as Pino insigne, the species grows well under a variety of conditions and produces fiber at an unusually rapid rate. During 1976, more than 105,000 ha of Monterey pine were planted, bringing the total area in plantation to somewhere near 500,000 ha. The current goal is to have planted 1 million ha by the end of 1981 (Chile Forestal 1976). This is an ambitious undertaking, but if the current planting trend continues, the goal should easily be realized. Protecting and managing these pine plantations offers a substantial scientific challenge to the Chilean land managers.

Monterey pine possesses some interesting characteristics that have important implications when assessing the effects of wildfire on stand mortality and development, and when considering the use of prescribed fire as a management tool.

Monterey pine cones are persistent and may remain attached to the tree for several years without opening (Roy 1966). Heat from a ground fire may be sufficient to open the cones, and the cones may open if their moisture content is reduced to less than 20 percent. Young trees, 15 to 20 years old, may produce abundant cone crops, and frequently, when a Monterey pine plantation burns, germination of the released seed may produce a stand that has several times more trees per acre than the planted stand. Under such conditions, as many as 500,000 to 1 million seedlings per acre may be produced

(Roy 1966). In this situation, the procedure has been to eradicate these seedlings when salvaging the burned stand, and then establish a new stand through planting.

Clearcutting followed by slash treatment using fire is becoming a common practice in Chile. Slash is occasionally windrowed, but broadcast burning is also common. Fire accomplishes two objectives. It removes the debris from the site and destroys the dense carpet of regeneration that may follow cutting.

Using prescribed fire in either young or mature stands presents some difficult challenges (fig. 1). Many of the plantations in Chile are planted at such close spacing that they are nearly impenetrable. This close spacing apparently does not materially effect the growth rate, but the species is not self-pruning and a heavy, dead needle drape occurs in the persistent dead branches that results in a hazardous condition of vertical fuel continuity and encourages destructive crown fires. Pruning could perhaps improve the

Figure 1--Twenty-year old Monterey pine plantation near Las Tablas in central Chile. Trees are 36 to 40 cm dbh and approximately 30 m tall. Note dense spacing and needle drape on the persistent branches.

situation but would be of doubtful economic benefit if the trees are to be utilized for pulp. Pruning would result in a deep bed of flashy fuel, and it remains to be determined if prescribed burning could be used to dispose of this material without causing unacceptable damage to the stand. The young trees have thin bark and even the older trees appear to suffer cambium damage from low intensity ground fires. Pruning, and disposal of the material, might be justified on the basis of keeping fire out of the crowns until initial attack suppression crews arrive on the scene.

Chileans have been fortunate to have been spared serious outbreaks of insects or disease in the Monterey pine plantations. There are a number of natural enemies of the species, and if they become serious, the monoculture currently practiced may need to be changed to break up the large continuous blocks of plantations.

Protection of these extensive pine plantations receives top priority by fire suppression forces. Although the job has not been easy, they have been reasonably successful. During the 1975-76 fire season, 4,553 ha of pine plantation were burned by wildfire (Ministerio de Agricũltura, Corporaciỏn Nacional Forestal 1976a). This was higher than normal but is still less than .01 percent of the total area in plantations.

Altieri (1977) provides some preliminary information on the effects of wildfire on a grass-shrub, Mediterranean ecosystem in central Chile. This type, along with other grass-shrub communities, exists between latitudes 30° and 40°, and fires are a common occurrence from December through March. Altieri suggests that fires in this type apparently set back the climax formation to a subclimax dominated by a shrubby plant community; that shrubs and annual grasses recovered quickly from the fires; and that even rodent, bird, and insect populations were not adversely affected by the fire.

Altieri tentatively proposes the use of prescribed fire for maintaining the present successional stage of the Mediterranean shrub type in central Chile. He bases this recommendation on the assumption that continuous exclusion of fire would permit the return of an "arboreous" fire-sensitive climax that would produce high volumes of fuel and higher intensity fires. My comment would be that if prescribed fire skills are developed, the work should be done in some of the more important commercial types. Because of the frequency and extent of wildfires occurring in this type,

there is little chance that much of the Mediterranean shrub type will progress out of the present stage of successional development.

Lenga (Nothofagus pumilio) is a native hardwood found growing in southern Chile, both in association with other species and in relatively pure stands (Chile Forestal 1977a). My observation on the effects of fire in these stands is limited to the Magallanes province in the extreme southern tip of Chile, and in particular to Tierra del Fuego, a portion of this province. The information I have is sketchy but may be summarized as follows. Mature Lenga stands are fire sensitive, low-growing, moderately dense and have a great deal of dead wood on the ground beneath them. During most of the year fires are difficult to start in these stands, even on the warmer, drier days. All the fires that start in this area are man-caused. These stands of Lenga grow in competition with extensive area of native grasslands. The grass is utilized heavily by some of the largest flocks of sheep found anywhere in the world. As a result, the managers of many of the "estancias" (ranches) are not adverse to burning some of these native Lenga stands to convert them to grass. However, the landowners do not set these fires indiscriminately. They recognize that, in addition to being an excellent source of energy for heating, the Lenga stands provide valuable cover for their flocks of sheep when strong winds sweep the open ranges. Evidence on the use of fire in this area indicates that the number of days per year when Lenga stands will burn are relatively few; but that if the conditions are right (winds in excess of 30 mph, temperatures in excess of 10° C, and relative humidities around 40 to 50 percent) the rancher may utilize headfires to burn long narrow strips that can then be cleaned up to provide additional grazing land for the sheep and firewood for domestic use.

Eucalyptus (Eucalyptus spp.) is one of the useful hardwoods found in Chile. It grows well in the Mediterranean climate and has been planted extensively throughout the central region for use on farms and in pure plantations. It is difficult to determine the area occupied by Eucalyptus plantations in the central region, but, in 1976, more than 2,600 ha were planted to Eucalyptus (Chile Forestal 1976).

According to available statistics (Ministerio de Agricultura, Corporación Nacional Forestal 1976a), 2 percent of the area burned is in Eucalyptus plantations, and additional hectares are probably burned in wildfires that consume native vegetation. Approximately 5 percent of the fires start in Eucalyptus plantations. Some species of Eucalyptus appear to resprout vigorously following cutting or fire. I was unable to determine if this was the case for the species of Eucalyptus found in Chile, but I did observe what appeared to be rather severe damage to plantations that were burned by wildfires. Fuels accumulate rapidly in these plantations due to the shedding of bark, leaves, and lower limbs. It is not known if prescribed fire could be used to maintain these fuels at a manageable level, but indications are that, at least in the very young plantations, fire would probably create damage that would be unacceptable.

There is another important Chilean conifer that deserves mentioning. The Araucaria pine (Araucaria araucana (Mol.) C. Koch) has recently been given total protection by the Chilean government as a result of unusually heavy exploitation that greatly reduced its abundance and range. The species is still found in isolated locations in central Chile but most of the accessible stands have been harvested and regeneration has not kept up with removal. I have no information concerning the role of fire in the regeneration or management of the species, and I mention it only to emphasize the possible need for research that will insure the protection and perpetuation of this native conifer.

PROBLEMS AND PROGRESS

Fire control in Chile has not been without its problems. However, in recent years, considerable progress has been made and Chile currently supports one of the most modern fire suppression organizations in South America. Both technical and administrative problems are being solved as newly trained people take their place in the fire control organization, and as the organization continues to gain experience.

As more plantations become established, more intensive protection measures will need to be applied to insure that these investments are adequately protected. The National Forestry Corporation may need to begin breaking up the large blocks of plantations to prevent the destructive large fires that continue to be a problem.

Because the pulp and sawlog rotations are so short, these same plantings are resulting in extensive harvesting operations that, in turn, produce large volumes of flammable fuels. These fuels must be treated before the area can be returned to production, and the responsibility for treating the slash may

need to be shared by the Forestry Corporation and the landholders. Prescribed fires that escape and spread into adjacent uncut plantations can not be tolerated.

Continued training is needed for crews from all agencies. The rapid shift toward fire problems that are associated with growing and harvesting pine plantations will require an intensive training program that will be vastly different from those used for controlling fire in native forest and brushlands.

Chile has recently experienced some extensive property damage as a result of wildfires sweeping into populated areas. In 1973, 220 homes were destroyed by a brush fire near Valparaiso. During December 1976 and January 1977, several large fires burning in this same general area were responsible for the death of one of the firefighters, the destruction of more than 30 homes and numerous head of domestic livestock (Chile Forestal 1977b). This appears to be primarily a fuels management-fire prevention problem, and steps are being taken to try to prevent a recurrence in this high hazard area.

Chile had no organized forest fire protection prior to 1962 when the Carabineros (National Police) were organized into forestry patrols. In 1965 the Minister of Agriculture authorized the formation of additional firefighting crews to support the National Police. Today the primary responsibility for fire control resides with the Minister of Agriculture, and the specific task is assigned to the National Forestry Corporation. Additional assistance is provided through the National Emergency Office, Minister of Interior and through the Minister of Defense (Ministerio de Agricultura, Corporación Nacional Forestal 1976b).

There are numerous ways to measure the progress of a newly organized fire control organization. One composite measure is in terms of number of fires, area burned, and average size fire. Chile has made substantial progress in each of these categories. Although numbers of fires have increased steadily, this probably reflects a continuing improvement in the detection and reporting system rather than a failure of prevention efforts. In spite of this increase in numbers of fires, the area burned shows a steady decrease. For example, during the 1971-72 fire season, 1,172 fires burned more than 82,000 ha for an average size fire of 70 ha. In 1975-76, 2,776 fires burned only 24,238 ha for an average of 8.7 ha per fire (Ministerio de Agricultura, Corporación Nacional Forestal 1976a).

Another measure of effectiveness is in the hectares of pine plantation burned by wildfires. Despite the substantial increases in hectares planted to pine, the portion of pine plantations burned has averaged around 5 percent of the total area burned each year. More recent information (Chile Forestal 1977b) for the 1976-77 fire season indicated that only about 1 percent of the total area burned was in pine plantation.

There are other ways to assess progress and effectiveness of the Chilean fire control effort. In fire prevention, the campaign that is activated each year before the fire season begins, and extends through the season, includes frequent TV and radio spot announcements, highway signs that ask for help in preventing forest fires, newspaper announcements, and elaborate, colored fire prevention posters that are distributed throughout the country (Ministerio de Agricultura, Corporación Nacional Forestal 1976a).

Fire detection has improved steadily, and during the 1975-76 fire season, nearly 75 percent of the fires were discovered by either air patrols or lookout towers (Ministerio de Agricultura, Corporación Nacional Forestal 1976a).

Progress is being made in the use of both fixed wing aircraft and helicopters in control of fires. During 1975-76, three PB4Y Catalinas, and three smaller aircraft were used for dropping water to support ground crew efforts. In addition, two Fairchild Hiller FH-1100 helicopters were used for helitack, patrol, and transport of personnel (Ministerio de Agricultura, Corporación Nacional Forestal 1976a).

Training of fire crews, fire overhead, and forest workers, have been given renewed emphasis with the opening of a new National Training Center for forestry and agriculture workers (Chile Forestal 1977b). New equipment and advanced training techniques have improved the skill-levels of both volunteer and regular firefighting forces.

Perhaps the most important indication of progress is reflected in the overall national program of organizing and dispatching trained fire suppression crews. The following tabulation summarizes the number of crews and total firefighters provided by the various agencies during the 1976 fire season (Ministerio de Agricultura, Corporación Nacional Forestal 1976a).

	No. Crews	Total Personnel
N.F.C.	84	1,408
Bomberos (Urban Firefighters)	90	1,815
National Police	21	332
Private Companies	58	967
Armed Forces	7	150
	260	4,672

The National Forest Corporation crews are of three types: volunteer crews made up mostly of high school-aged boys, semiprofessional crews made up of forest workers employed by N.F.C., and professional crews that are highly trained N.F.C. employees working almost exclusively on control and use of fire.

It wasn't by accident that, in 1968, the Chilean foresters responsible for fire control in the country began negotiation to purchase the equipment needed to adequately protect the country from wildfires. In 1972, the Chilean government received an extensive shipment of some of the most modern fire control tools available. The shipment included a wide variety of hand tools, portable and base-station radio equipment with testing and maintenance facilities, a large selection of water handling equipment including portable pumps, slip-on tanks, hose and storage tanks, and buckets for dropping water from helicopters. This array of equipment has made it possible to adequately equip not only the National Forestry Corporation crews but to provide some equipment for the National Police, Bomberos, Industrial, and Military crews as well.

Finally, there are some obvious areas where a program of well-planned fire research could yield some rather significant benefits. Research is needed to develop guidelines for using fire in the management of Monterey pine. The importance of the species and the potential benefits that may be derived make this a top priority item for fire research. This research should also include studies of the effects of single and multiple prescribed burns on physical and chemical soil properties. In conjunction with these studies, fire effects research should be started to determine if fire has a part to play in the management of some of the native plant species, of certain wildlife habitats, or in the improvement of forage for wildlife or domestic livestock.

Improvements, based on some well-defined studies, should be made on the system being used for rating and describing the levels of Forest Fire Danger. Some work is being done on this problem, but the effort so far has been toward the adaptation of Fire Danger Rating Systems that are in use in other parts of the world. General fire weather forecasts are available through the Chilean National Weather Service, and these could be further refined to more adequately support the Fire Danger Rating System.

With the continued emphasis on pine plantation culture, research is needed to prepare guidelines for the location, construction, and maintenance of fuel breaks that will break up the large continuous blocks of plantations and protect them from fires moving in from outside the blocks.

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FIRE PROTECTION AND FUEL MANAGEMENT ON PRIVATELY-OWNED WILDLANDS IN CALIFORNIA[1]

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Abstract: California's 60 million acres (24.3 million hectares) of wildland include high values of natural resources and intermingled values of life and property. Wildfire is one continuing threat to the destruction of these values. Because the general public benefits from the resources, the State has assumed the financial responsibility for protecting those resources which are located on privately-owned wildlands from being damaged by fire. This paper describes the nature and complexities of the system of fire protection provided to those lands by the California Department of Forestry in cooperation with many other local, state, and federal agencies.
Key words: Fire Protection, fuel management, wildlands, California

INTRODUCTION

California has some 60 million acres (24.3 million hectares) of so-called "wildlands," consisting of forest, brush, and grass covered lands. These wildlands include resource values of timber, forage, water, soil, recreation, aesthetics, and wildlife, all of which are essential to the economic and social well-being of the State's population. The wildlands also include intermingled values of life and property. Wildfire is one continuing threat to the destruction of these values.

Damaging wildland fires occur every year in California. The State's environmental conditions, typical of Mediterranean-climate ecosystems, add up to a recipe for fiery disaster: continuous expanses of highly flammable trees, brush, grass and other vegetation; rugged terrain; long periods during the summer when there is little or no rainfall; dry north and east winds during the critical wildland fire season; and an increasing population that insists on seeking living space and recreation in nature's beautiful but highly flammable wildland.

High-intensity wildfires destroy not only the on-site resource values but also, by generating an increased rate of removal of top soil through both dry and wet erosion, can cause off-site damages to downstream improvements by flooding and siltation. And they frequently take the lives of people (Phillips 1971).

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To alleviate this threat of damage by wildfires, a number of fire protection agencies protect various portions of the State's wildlands. These agencies include the California Department of Forestry (CDF); several federal agencies: U. S. Forest Service, Bureau of Land Management, National Park Service, Corps of Engineers, and the federal military agencies; and the so-called "Contract Counties" of Kern, Los Angeles, Marin, Santa Barbara, and Ventura.

The record of wildfires in 1976 on the 60 million acres of federal, state and privately-owned wildlands was fairly typical of recent years. Last year 13,339 wildfires burned over some 194,000 acres (78,543 hectares). Of these numbers, 8,672 fires occurred on privately-owned lands directly protected by the CDF and damaged resources and property values on 153,247 acres (62,043 hectares) of wildland.

THE ORGANIZATION OF FIRE PROTECTION ON PRIVATELY-OWNED WILDLANDS

The State of California has declared the protection from fire of natural resources on certain privately-owned wildlands to be of statewide interest and has assumed the financial responsibility for the protection. These lands, comprising some 33 million acres (13.4 million hectares), are defined by law and delineated on official maps as "State Responsibility Area." Under the direction of the State Board of Forestry, the CDF performs a major review of these lands every few years, and annually accounts for minor changes in land-use patterns and in the boundaries of incorporated cities. About 24 million of these acres (9.7 million hectares) are protected directly by the CDF; about 4.5 million acres (1.8 million hectares) located within the National Forests are protected by the U. S. Forest Service under contract to the State; about 0.5 million acres (0.2 million hectares) are protected by the Bureau of Land Management in northeastern California under an offset agreement by which the CDF protects a like area of the Bureau's land; and about 4 million acres (1.6 million hectares) are protected under contract to the State by the counties of Kern, Los Angeles, Marin, Santa Barbara and Ventura. Overlying some 6 million of these acres (2.4 million hectares) are about 360 local government fire protection districts. Fire departments in these districts are organized primarily to protect life and property from fire but also lend important assistance on wildland fires. In turn, they receive aid on structural fires from the adjacent wildland protection agencies (Neal, Taylor, and Helm 1974).

In addition to the 24 million acres of State Responsibility Area, the CDF also directly protects about 4 million acres (1.6 million hectares) of intermingled federally-owned lands under contract to the responsible federal agencies. The number of wildfires occurring on the CDF's area of direct protection has increased almost steadily since the early 1960's. This trend will probably continue as the State's population increases and more people seek living space and recreation in wildland areas.

THE CDF'S PLAN OF FIRE PROTECTION

To meet its legal responsibilities of providing fire protection to privately-owned wildlands and intermingled federally-owned lands, the CDF's goal of fire protection is to keep fire damages to resources and exposed life and property at or below a level which is acceptable within economic, social, political and ecological constraints. The CDF endeavors to meet this goal by optimally allocating its annual budget to a balanced and integrated system of fire prevention, fire defense improvements, fire suppression, and support functions.

This system of fire protection is derived from what is known formally as the "California Department of Forestry's Fire Protection Plan." This plan is required by law and must be approved by the Board of Forestry. It includes goals and objectives, standards of performance, and measures of effectiveness for each element and unit. The plan is not static. It is continually changing in scope and organization to meet changes in the needs for fire protection, in land-use patterns, in fiscal constraints of current administrations, and in the social and political expectations of the people. It strives to use the principles of "master planning" as developed by the National Fire Prevention and Control Administration (USDC-National Fire Prevention and Control Administration 1977).

The CDF's plan for protecting privately-owned lands is based primarily on a measure of the resource values being protected from damaging fires. Other inputs include the probability of fire-starts, expected fire behavior, and auxiliary factors related to the "difficulty of control." The plan is constrained by the legal requirement to abate <u>any</u> uncontrolled fire as a public nuisance. It is also constrained by the need to provide both strong initial attack on local fires and in-depth follow-up assistance to large fires and to multiple-fire situations anywhere in the State. Since fire danger varies greatly both in time and location within the State, protection forces in one region may become the backup for regions having more critical fire danger or a number of major fires in progress.

Like all fire protection agencies, the CDF relies on cooperative effort at many levels. By law, the landowner is required to perform certain actions of hazard reduction and to take certain precautions in the use of fire; the degree of compliance with these laws has not always been perfect (Taylor and Neal 1973). The local governments (i.e., counties, cities, and special taxing districts) have been given guidelines for enacting ordinances designed to protect rural and mountain communities from encroaching wildland fires and to prevent the spread of fires from the communities into the wildlands (County Supervisors Association 1965); the enactment of these ordinances and their enforcement also have been something less than perfect (Neal and Taylor 1973). Recent actions by local governments in response to the California Environmental Quality Act of 1970, however, have given new impetus to this program; the Safety Elements of many counties' General Plans now include provisions for better measures of fire protection, including the zoning of critical fire hazardous areas (Helm, Neal, and Taylor 1973).

Beyond the actions of the private landowner himself and of local governments, the CDF's plan of fire protection for privately-owned wildlands relies heavily on mutual aid from adjacent cooperating agencies when fire emergencies progress beyond the CDF's capability. In turn, the CDF lends assistance to its neighbors upon request. Disasters do occur, however, when even this local mutual aid is not enough. When the fire situation appears to be getting entirely out of hand, the Governor can declare a "state of emergency." At that time all fire departments in the State are required by law to provide aid, in accordance with their capability. Coordination of fire protection activity during such a period of declared emergency is provided by the State Office of Emergency Services. If an emergency gets beyond the combined capabilities of all agencies within the State, then the Governor may ask the President of the United States to declare a major disaster and to provide federal assistance through the federal Office of Emergency Preparedness. Depending on the nature and extent of a fire situation, there is therefore a planned build-up of assistance from the local, to the state, and finally to the federal level. This total system of mutual and outside aid was implemented during California's fire disaster in 1970 (Phillips 1971).

THE CDF'S SYSTEM OF FIRE PROTECTION

To implement its plan of fire protection, the CDF is organized with the Director's Headquarters in Sacramento, five Region Headquarters, 23 Ranger Units, and 116 Ranger Districts. In the 1976-77 fiscal year, the CDF's budget for protecting privately-owned wildlands was $67 million.

Fire Prevention

"Fire Prevention" is the first order of business in the CDF's fire protection system. Fire prevention includes three components: (1) Education, (2) Engineering, and (3) Law Enforcement. "Education" is essentially the "Smokey Bear Program." It is designed to educate the public through a variety of media in how to use fire carefully and to prevent the start of wildfires. "Engineering" deals primarily with the elimination or control of sources of ignition or of materials that can be ignited. It includes the reduction of the volume and continuity of vegetation around structures, along roads, and along public utility rights-of-way to prevent fires from spreading from the original point of ignition. It also includes the "Fire Safe" program which provides guidelines for fire safety to entire communities, as well as to individual homes (County Supervisors Association 1965). "Law Enforcement" deals with the investigation of how fires start and with the enforcement of the State's laws and regulations pertaining to the prevention and use of fire in the wildlands. All CDF employees are trained and are expected to participate in various aspects of the fire prevention program. In addition, the fire prevention program enlists the direct assistance of private industry, other governmental agencies and interested citizens in the actions of the California Fire Prevention Committee. The CDF also relies on the assistance of private citizens and service groups in its Red Flag Program, designed to alert everyone to the extreme fire danger during periods of actual, critical fire weather.

Detection

"Detection" provides for the location and reporting of wildfires. Presently the CDF's detection system includes a network of 78 fixed lookouts, located on mountain tops throughout the CDF's direct protection area, and surveillance aircraft in two areas where detection from fixed lookouts is spotty. The CDF also depends on the receipt of alarms from the general public and from the lookouts of adjacent fire protection agencies. The CDF is continually seeking alternatives to its present detection system, including the possible use of infrared detection or other techniques of

remote sensing from aircraft or from fixed-position satellites.

Dispatching

If fires are detected, they are reported to the CDF's "Emergency Command Centers" located at each of the 23 Ranger Unit Headquarters. If the type of fire is known, the Command Center personnel dispatch the ground and air attack units which they feel are needed to control the emergency. If the type of fire is not known--i.e., if only "smoke" is reported-- then the Command Center personnel refer to the "running card" which has been prepared for the area. The running card lists all attack units which should respond in accordance with the fire danger at the moment.

Ground Attack Units

"Ground attack units" include various models of fire engines, bulldozer-transport units, and conservation camp crews. Some 361 fire engines are located at 229 fire suppression stations. The CDF's fire protection plan includes a five-person response as the standard for optimum safety and effectiveness of engine companies. The CDF is currently budgeted, however, to provide only a three-person response on all engines (one crew leader and two fire fighters). Fifty-three large bulldozer-transport units (Caterpillar D-6 or equal) and 25 medium units (Caterpillar D-4 or equal) are distributed throughout the CDF's area of direct protection. There are 36 conservation camps located in the State, each having 60 to 80 inmates or employees of the California Conservation Corps. About 40 percent of the time available from manpower assigned to these camps is used to assist in suppressing wildfires through follow-up action or to build fire defense improvements, such as fuelbreaks.

Air Attack Units

"Air attack units" include air tankers, helitack crews and air attack coordinators. The CDF contracts for 21 air tankers, and the U. S. Forest Service contracts for 15 air tankers located at a total of 18 air attack bases throughout the State; these aircraft are used on initial attack by either agency, interchangeably. Coordinators are located at each of the CDF's 13 air attack bases to direct the suppression activities of the air tankers. The CDF has seven helitack crews, all located in northern California; on-duty response of each crew includes one crew leader, one assistant crew leader, and three fire fighters.

Fire Defense Improvements

To assist in its fire suppression efforts, the CDF has constructed a system of "fire defense improvements," including roads, trails, fuelbreaks, fuel modification, water cisterns, communication facilities, and other service facilities. The objective of these prepared systems is to improve the capability of fire fighting forces at the time of a fire emergency.

Fuel Management

"Fuel management" is one component of the fire defense improvements element of the CDF's fire protection plan. For the purpose of that plan, fuel management is defined as "the planned treatment or manipulation of naturally growing vegetation or any other flammable material for the purpose of reducing the rate of spread and/or the output of heat energy to be expected from any wildfire that might occur in the area being treated." Fuel management must always be considered an integral part of overall vegetation management and land management and must be compatible with a large and complex set of social, ecological, legal, and economic goals and constraints.

Fuel Buildup

Extreme fire hazards because of heavy volumes of flammable fuel exist on privately-owned wildlands in California. These hazards have increased over the years because of a public policy of fire exclusion and fire control; because of the reluctance of timberland owners to use fire to dispose of slash where damages might occur to reproduction and young-growth trees; because of the damages that uncontrolled fires might inflict on life, property and resources; and because of many people's opinion that "all fires are bad."

In the eyes of a fire fighter, it is rather evident that steps should be taken by the landowner or by the CDF to decrease these hazards so as to reduce both the probability of disastrous conflagrations and the cost of controlling them. But programs of fuel management must be conducted differently on privately-owned wildlands than on federally-owned lands. Federal land-management agencies can formulate and implement needed programs of fuel management, although within constraints of policy and law. There is no law in California, however, that enables the CDF to declare that an extraordinary

fire hazard exists on a piece of privately-owned land because of vegetative conditions and then to take measures to reduce that hazard. Nor does the CDF seek such a law. There are State laws, however, which either mandate (in some cases) or permit a landowner to reduce the fire hazard on his property.

Hazard Reduction Laws

Several laws mandate that any person who owns structures in the wildlands must take certain measures of hazard reduction to prevent fires from spreading from the structures to adjacent wildland vegetation or to prevent encroaching wildland fires from igniting the structures. Other laws require clearances along powerline rights-of-way and around refuse dumps. The CDF and its contracting agencies are responsible for enforcing these laws. Penalties can be applied for non-compliance.

Fuelbreaks

With the permission of landowners, the CDF can and does construct and maintain "fuelbreaks." A fuelbreak is a strategically-located strip of land along which heavy fuels are replaced with lighter fuels for the purpose of breaking up vast, continuous expanses of brush or other heavy fuels. The fuelbreaks provide safer access for fire fighters and their equipment and provide a relatively safe line for controlling spreading fires. Statewide, the CDF has some 1,650 miles of fuelbreaks in its system of fire defense improvements. They have proven to be highly valuable in most fire situations, although fires can easily sweep across them under conditions of high-speed föehn-type winds (USDA-Forest Service 1973).

Range Improvement Program

Laws which spell out California's so-called "range improvement program" are intended primarily to enable private landowners to use prescribed burning to convert brush-covered lands to more useful grass. The laws declare that the program also has public benefits which relate to the reduction of the fire hazard, increased production of water, and improvement of wildlife habitat. Because of these public benefits, the laws state that the CDF shall provide certain assistance to the landowners. Among other things, the CDF gives counseling service, prepares the permits which are required for any use of fire by a private landowner, and provides standby fire fighting forces at the site of a burn for the purpose of controlling any escaped fire.

The landowner must prepare the control lines, ignite the fire, and provide all personnel and equipment needed to spread the fire safely and to keep it within the intended bounds. The landowner is also responsible for any damages that might occur to adjacent properties as the result of escaped fire. If willful negligence is the prime cause of an escaped fire, he may also be liable for the CDF's costs of suppression. The costs to the landowner of preparing and conducting range improvement burns and of purchasing liability insurance, together with a number of other reasons, have caused the program to decline in recent years.

The following table illustrates the main results of the range improvement program since its beginning in 1945 through 1976:

Total number of burns under permit.	9,120
Total acres burned under permit.	2,613,462
Excess acres burned by escaped fires.	194,704
Acres reburned under permit . . .	818,483
Acres seeded with grass	766,429

The program reached its peak in 1954 when some 227,000 acres were burned. In recent years activity has decreased, with a low point reached in 1973 when only 18,000 acres were burned.

Changes in Attitudes and Practices

Most private and public land managers in California agree, however, that some form of fuel management does indeed have a place in overall land management. Changes in both attitude and practice seem to be occurring. Effort is being made, for instance, to more fully utilize or to dispose of residual material left after timber harvesting and other woods operations. Prescribed fire is beginning to be used increasingly to reduce the volume of flammable fuel or to maintain desired ecosystems. With increased awareness that our reserves of oil and gas may not last forever, wood is once more being studied as a potentially major source of energy. The CDF has been reviewing its past policies of fuel management on privately-owned wildlands and will be proposing to the Board of Forestry

a new program intended to meet more closely the needs of today.

Support Services

Supporting the CDF's fire prevention and suppression efforts are the functions of research, training and other support services. The CDF works cooperatively with other wildland fire protection agencies and with private industry to develop new knowledge, techniques and equipment to increase its effectiveness in fire protection. The Department has an extensive training program to provide its permanent and seasonal employees with that knowledge and those techniques which enable them to perform their fire protection jobs more safely and effectively. Of prime importance in this training program is the CDF's Fire Academy which can accommodate up to 100 trainees at a time. Support services also include an extensive communications network; a system of fire weather observing stations (some of which are now automated, transmitting their data via the GOES satellite); fire weather forecasting provided by the National Weather Service; and the analysis of fire reports which enables the CDF to replan and reorganize its forces to meet its fire protection objectives most effectively and efficiently.

Mutual and Outside Aid

As described earlier, the CDF depends upon cooperating agencies for mutual assistance when fire emergencies progress beyond its capabilities. In turn, the CDF provides mutual assistance to its neighbors upon request. Without this interagency effort, no one agency could hope to perform the total job of fire protection for which it is responsible.

CONCLUSION

The problem of damages by wildfire to life, property and natural resources remains with us. Following California's major fire disaster of 1970, an interagency task force was formed by the State to identify the principal problems facing wildland fire protection agencies and to make recommendations to solve those problems (Division of Forestry 1972). Most of the recommendations have been implemented through cooperative action of a large number of public and private agencies and individuals. Still other recommendations are being tested by the slower process of political debate and legislative action. The net sum of the task force's efforts, however, have been of substantial and lasting benefit to the protection from fire of privately-owned, as well as publicly-owned, wildlands in California.

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A FIRE BEHAVIOR INFORMATION INTEGRATION SYSTEM FOR SOUTHERN CALIFORNIA CHAPARRAL [1,2]

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Abstract: A Fire Behavior Information Integration System was developed for southern California chaparral ecosystems; it provides storage, retrieval, display, inference and integration of site, vegetation, fuels, cultural and hydrological information needed to simulate fire behavior and consequences. The system applies the techniques of gradient modeling developed in Glacier National Park (Montana) by linking a site inventory, gradient matrix fuel models and computer software. Following system development, it was used to test the effects of four site inventory resolution levels, and to evaluate the potential for generating the site inventory data base directly from LANDSAT satellite imagery. The expansion of this systems approach to an integrated network of models and simulators and the development of a forest management simulation language (FORPLAN) are considered.

Key words: gradient modeling, chaparral, resource inventory, fire management, FORPLAN, FIRESCOPE, LANDSAT imagery

INTRODUCTION

Gradient modeling is a computer-based resource modeling technique developed in Glacier National Park (Montana) which provides resource information storage, retrieval, display, inference and integration for fire simulation and land management purposes. Rather than dealing with the landscape and its biota as sharp, discreet units, gradient analysis describes and quantifies continuous variation that corresponds to various spatial and temporal environmental gradients. Gradient modeling is thus an application of gradient analysis and ordination (rather than habitat classification) to resource modeling (Kessell 1976a, 1976b, 1977a, 1977b). It builds upon the wide theoretical and analytical base of direct gradient analysis, which arranges samples and community characteristics along predetermined gradients such as elevation and stand age (Whittaker 1967, 1973a, 1973b), and indirect gradient analysis, or ordination, which uses various mathematical techniques to arrange samples or community attributes based on compositional similarities (Bray 1956, 1960, 1961; Bray and Curtis 1956; Gauch and Whittaker 1972; Whittaker and Gauch 1973; Kessell and Whittaker 1976; Noy-Meir and Whittaker 1977). We have found gradient concepts particularly applicable to the development of fuels- and fire-oriented information systems (Kessell 1977a, 1977b; Kessell and Cattelino 1977).

A gradient modeling system, such as the southern California Fire Behavior Information Integration System (FBIIS) described here,

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[1] Presented at the Symposium on Environmental Consequences of Fire and Fuel Management in Mediterranean Ecosystems, Palo Alto, Calif. Aug. 1-5, 1977.

[2] Portions of this paper were adapted, by permission, from "Evaluation of a Fire Behavior Information Integration System for southern California chaparral wildlands" by S. R. Kessell and P. J. Cattelino, which will appear in Environmental Management 2 (2),

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includes three major components:

1) Gradient models of the vegetation and/ or flammable fuels which express community properties (fuel loadings, community characteristics or species importance values) as functions of environmental gradients;

2) A site-specific inventory system which is coded from remote records such as aerial photos or satellite imagery, topographic maps and disturbance histories. Each site inventory record includes the stand's rectangular coordinates and certain key site parameters which give the stand a unique location within the environmental gradient space described in (1) above; and

3) Appropriate computer software which links the gradient models and site inventory to provide data storage, retrieval, display and inference.

For example, a very simple gradient model designed to predict the amount of flammable fuel on hectare sites might include a gradient model which expresses fuel loadings as a function of formation type and stand age, linked with a site inventory which stores each hectare's formation type and age.

Gradient models may be extremely refined, such as the six-gradient Glacier National Park system which coded site inventory resolution down to 10 m; alternatively, the southern California FBIIS described here tested site inventory resolution levels as crude as 1,000 m (100 ha blocks). Regardless of resolution level, the purposes of such systems include: 1) storage of site-specific resource data; 2) retrieval and display of these data; 3) combination of these data with inference models to predict parameters (such as species composition or fuel loadings) not included in the site-specific inventory; 4) storage and retrieval of other data, such as cultural and hydrological information, which will be of value to the system's users; and 5) linkage with other systems and models (such as fire behavior models, succession/effects models and land management planning systems) to provide further inference and simulation capabilities. Specifically, for fire management purposes, it is desirable to interface the gradient modeling information system with fire behavior models which predict fire characteristics from site, fuel and weather inputs (Rothermel 1972; cf. Kessell 1976a, 1977a). Such a system can then automatically integrate the basic data required for fire simulations, and thus provide users with fast, accurate estimates of potential fire behavior and effects.

CONSTRUCTION OF THE SYSTEM

Construction of the FBIIS required the development of a remote site inventory appropriate to the southern California area and available remote data sources, appropriate gradient models of the flammable ground fuels, and a source program - data storage package linking these components. The model has been implemented for a 140 sq km prototype area located primarily within the Angeles National Forest northeast of Glendora, Calif. While the area is predominantly a mosaic of chaparral, grass and oak enclaves between 300 and 1,100 m elevation, the north portion includes forests extending to elevations of 2,300 m.

Remote Site Inventory

The remote site inventory provides a methodology and digital data base for storing key site-specific data which are recorded from aerial photographs (1:100,000 scale false color infrared vertical photos from U-2 aircraft), 7.5' USGS topographic maps and disturbance history. It thus provides the site parameters required by the fuel models to infer fuel characteristics. Information coded on a stand by stand basis includes primary and secondary cover (formation) type, primary and secondary topography, aspect, elevation, fire history, hydrological features and all cultural development. The basic system codes a separate record for each hectare (squares with sides = 100 m), blocks these records within sq km (100 ha) areas indexed by Universal Transverse Mercator (UTM) coordinates, and provides within-site resolution down to 0.25 ha. The record format and coding procedures are given in Kessell and Cattelino (1977). Field verification of the remote site inventory code was conducted by ground visits to over 250 one ha stands. The only error detected was the failure to note secondary vegetative cover types of "oak enclave" (with 30 - 35 % cover) in seven canyon habitats.

The use of these site data for information retrieval and fuel inference is discussed below, while the effects of alternative resolution levels and different remote data sources are discussed in later sections.

Gradient Fuel Models

The gradient fuel models were devised to provide fuel inference capabilities (loads by fuel types and packing ratios by strata) using available ground truth fuels data and input parameters provided by the remote site inventory described above.

Although three- or four-gradient models were sometimes required to describe coniferous forest fuels in Montana (Kessell 1976a, 1977b; Jeske and Bevins 1976), the availability of ground truth fuels data from southern California did not permit such an ambitious attempt. Instead, two gradients, vegetative cover (formation) type and stand age, were used to construct a 5 x 11 matrix for each fuel type's loading and for each stratum's packing ratio. Fuel loads are differentiated by three major fuel types of branchwood, shrub foliage and grass + forbs. Branchwoods are further grouped into five diameter classes based on the time lag in their responses to changes in atmospheric moisture.

The fuel gradient models are given in Kessell and Cattelino (1977). Stand age is represented by an 11-element vector of five year increments, with all stands over 50 years old grouped as "mature" (last element). Cover types from the remote site inventory are grouped into five major vegetation types: grass, soft chaparral, hard chaparral, broadleaf forest and coniferous forest. Chaparral fuel loadings were determined from Rothermel and Philpot (1973) and unpublished data provided by the Riverside Fire Laboratory. Grass fuels were modified from the National Fire Danger Rating System's "A" (grassland) fuel model (Deeming et al. 1972) to permit grass and forb build-up during the first 15 years following a fire. Coniferous forest fuels were determined by extrapolating extensive fuels data collected in Montana (Kessell 1977b; Jeske and Bevins 1976). Successional broadleaf forest fuels closely mimic hard chaparral fuels, while mature broadleaf fuels are based on Rothermel (1972) and Deeming et al. (1972).

Software Package

The FBIIS software package was developed on a small on-site digital computer (Hewlett-Packard 2000) with 32 K core storage, single disk drive, single magnetic tape unit and interactive input/output terminal. Although this system was adequate for the prototype model, implementation of the FBIIS for a large area would be more efficient on a large time-sharing computer facility.

The software package consists of a large magnetic tape file which includes the fuel models, program dictionaries and 140 sq km site inventory, and a single (1400 line) FORTRAN IV interactive source program. Use of the FBIIS requires simply a log-on to the system, mounting one magnetic tape and a single execution command. All other required input and specifications are prompted by the interactive program.

The user may select one of two operating modes: individual hectare mode or statistical summary mode. Six information retrieval/inference options are available for each mode: site-terrain, vegetative cover, flammable ground fuel, cultural features, hydrological features and firebreaks. Individual hectare mode provides data retrieval and inference on a stand by stand basis for any selected area. Statistical summary mode provides a statistical profile for any specified combination of sq km (100 ha) areas. Sample output showing all options and both operating modes is included in Kessell and Cattelino (1977).

Site-terrain, vegetative cover, cultural and hydrological information display results from simple retrieval, interpretation and summary of the stored remote site inventory data. Cultural and hydrological features are further summarized for each quadrant of each sq km selected. Firebreak summaries give the location of both artificial and natural firebreaks (stands whose only cover is "barren").

Fuels data are inferred by linking the site inventory data with the gradient models. Thus, a cover type of "grass" and stand age of "28 years" defines a single element of each gradient matrix model (and therefore a deterministic set of fuel loadings and packing ratios). When two cover types are coded for a single ha, the program assumes that the predominant cover occupies 70 % of the stand, while the secondary cover occupies the remaining 30 %; a weighted average is computed and displayed. Fuels information in the summary mode is obtained by solving fuel parameters hectare by hectare, and then converting the results to a mean, sample deviation and confidence intervals for each fuel parameter.

A useful feature of the fuels module is that it requests the current data from the user, compares this to the date each sq km's site inventory was coded, and increments the stands' ages by the difference. Thus the system constantly updates itself, and requires only annual entry of areas burned during the last fire season (these areas are set back to age = 0). In addition, by incrementing the date artificially, the user can project future fuel increases and their associated fire hazard.

EFFECTS OF DEGRADING THE SYSTEM'S RESOLUTION

Once the basic FBIIS became operational, we tested the effects of various levels of site inventory resolution on the summary mode's fuel inference errors and implementation costs. Three alternative resolution levels of 4.0, 11.1 and 100.0 ha were selected; to evaluate

each resolution level, a representative six sq km portion of the study area was re-coded for each new resolution level. Except for the changes to the grid size, coding procedures were identical to those used for the basic one ha resolution FBIIS. For each resolution level and sq km, statistical fuel summaries were computed.

Results showed that degradation of resulting summary fuels data depended greatly on the uniformity of vegetative cover and stand ages within each sq km. Uniform areas suffered minimal degradation, whereas areas of patchy vegetative cover sustained considerable fuels inference degradation. Much of the study area contains areas of uniform stand age and predominantly chaparral cover, which handled resolution degradation very well. For example, a test area in Marshall Canyon (UTM 3780 N, 431 E; cf. Kessell and Cattelino 1977) showed little fuel inference loss at the 4 ha resolution level; even the crude 100 ha grid gave fuel errors which departed less than one standard deviation from the one ha grid's predictions.

Alternatively, resolution degradation had much greater effect on fuels inference from Coldwater Canyon (UTM 3791 N, 435 E). This 1,600 m elevation area includes a diverse cover mosaic of hard chaparral, forest, forest enclave, barren and soft chaparral (listed by decreasing importance). Here even the fine branchwood fuels predicted by the 4 ha resolution FBIIS average about 0.6 standard deviations from the one ha system's predictions, while considerably greater fuels degradation is observed at the lower resolution levels. Detailed results appear in Kessell and Cattelino (1977).

During the conduct of this study, we were surprised by how well the crude 100 ha FBIIS performed in areas of uniform vegetative cover. We thus expanded the tests of the 100 ha resolution level to a 75 sq km area which traversed the entire study area. We also compared the errors of the 100 ha FBIIS (deviations from the one ha FBIIS' predictions) to the errors incurred by the current operational method of assuming that all land is covered by chaparral (to see if the 100 ha FBIIS offered improvement over the chaparral assumption method). Results showed that for the fine branchwood and shrub foliage fuels which propagate a fire, the average errors of the 100 ha FBIIS were within 0.6 standard deviations of the one ha system's predictions. The 100 ha system performs less well for the larger fuels; however, the 100 ha FBIIS still reduces by half the errors incurred by the method of assuming chaparral cover throughout the area. Thus the results show that even the crudest FBIIS offers a considerable improvement and refinement over existing fuel inference methods, and could well provide a minimum base-line resolution level for future system development. Again, detailed results appear in Kessell and Cattelino (1977).

We also noted considerable financial savings by use of the lower resolution levels. The relationship between resolution level and site inventory coding costs is approximately inverse square-root (that is, degrading the resolution level by a factor of four reduces the cost by a factor of two). This non-linear relationship is due to fixed activities and costs which are independent of resolution level (locating materials, transferring coordinate grids and fire histories, and field checking the results). Comparative costs for coding the four resolution levels are:

Resolution level	Cost per ha
1.0	$ 0.25
4.0	0.10
11.1	0.06
100.0	0.02

SATELLITE IMAGERY AS A SITE-SPECIFIC DATA BASE

Due to the broad availability of vegetation cover data from satellite imagery such as LANDSAT (see Heaslip 1976 for LANDSAT-ERTS review), we conducted preliminary tests to determine if such imagery could provide the remote site inventory data required by the FBIIS. The results were not reassuring.

Space limitations do not permit inclusion of detailed methods and results here; they are provided in Kessell and Cattelino (1977). In summary, the FBIIS' site inventory was coded for a nine sq km area (in the Santa Monica Mtns. north of Los Angeles) from both interpreted LANDSAT imagery (Nichols 1974) and the U-2 infrared photograph method described above. The best LANDSAT-derived inventory resolution equaled the four ha resolution FBIIS, but could not match the one ha resolution FBIIS. Furthermore, the vegetative cover correspondence between the U-2 photos and satellite imagery methods was only 54 %. It was not possible to field check in the Santa Monica area due to fiscal and time constraints, and the interpreted LANDSAT imagery was not available for our study area; however, the virtually 100 % accuracy shown by field checks of the U-2 coded FBIIS within our study area (described above) makes the LANDSAT cover data suspect.

Certainly more work and more detailed comparisons are needed to determine the applicability and limitations of satellite imagery in the construction of fire information system data bases. In the meantime, we strongly urge detailed local comparisons and field verification before potential users rely on such imagery for the construction of site-specific data bases. The reader is referred to Kessell and Cattelino (1977) for further details.

CONCLUSIONS
FIRE, INFORMATION, SYSTEMS AND FORPLAN

Gradient modeling, developed in Glacier National Park as the first systems application of gradient analysis to resource management problems, has been categorized by its detractors as an expensive, high resolution method which lies beyond many managers' needs and budgets. Yet the development of the FBIIS described here has demonstrated that gradient modeling techniques can offer a flexible, user-oriented and cost-effective management package at the commonly-required resolution levels of one to 100 ha. Despite the obvious differences between the Glacier and southern California systems, the technique of linking a remote site inventory with environmental gradient models of plant species, animal species, community characteristics or fuel properties is an effective inference method; it should find applications beyond the fuels - fire modeling realm.

A system such as the prototype southern California FBIIS also offers considerable expansion potential. For example, current use of the system requires display of site and fuels data, which are then re-entered with weather parameters as input to fire behavior models. Fire behavior estimates, including spread rate, intensity and flame length, can then be calculated; these may in turn be re-input to (developing) fire effects models, which may also require vegetation descriptions available from the initial FBIIS site inventory. Cooperative work has been proposed to quantify the distribution of plant species and community characteristics along three major gradients (elevation, topographic-moisture and stand age) for a 1.5 million ha area of southern California; completion of this work will both greatly expand the inference capabilities of the FBIIS, and provide the necessary data base to further develop and refine fire effects models. Availability of these data and applications offers still more possibilities for system expansion and refinement.

To illustrate this process of system expansion, recent cooperative work between Gradient Modeling, Inc. and the Northern Forest Fire Laboratory (Missoula, Mt.) has used similar data bases and models for coniferous forest ecosystems to construct new systems components, including:

1) a sensitivity analysis of fire behavior models under a wide range of fuel and weather regimes, which allows conversion of fuel errors to fire behavior prediction errors (Kessell _et al._ 1977);

2) a fire hazard evaluation system (TAROT) which links fuel accumulation models, cumulative weather distributions and a fire behavior model to quantify temporal increases in fire hazard (Bradshaw 1977; Kessell _et al._ 1977);

3) a forest stand simulator (GANDALF) which projects the effects of thinning and/or burning on the stand's stocking, mortality, natural and activity fuels, understory vegetation and fire hazard; and

4) a methodology (FMIIS) for selecting the required resolution and accuracy of landform, fuel and meteorological inputs to fire behavior systems, given specified levels of predicted fire behavior accuracy and resolution.

Such new tools and models allow us to expand our understanding of fire and its effects, better utilize our existing data bases and systems, and generally offer better, more precise information to the land manager. Yet at the same time, this plethora of and seemingly exponential increase in methods, models, simulators and systems are often overwhelming the poor manager who has a simple, straightforward fire management problem -- we seem to be rapidly reaching the point where the manager may inadvertently call in the Third Cavalry Division when he could have done the job with a sling shot ! Clearly this is a problem all of us, researchers and managers alike, must soon face; we hope that tomorrow's workshop "Facilitating Communications Between Researcher, Manager and the Public" can help us bridge this most uncomfortable communications gap.

On the assumption that the responsibility falls upon the researcher, Gradient Modeling, Inc. has recently initiated the development of FORPLAN, a FORest Planning LANguage for coniferous forest ecosystems. FORPLAN is not a model or simulator; rather, it is a user-oriented forest management simulation language consisting of 25 - 30 common English words. Upon implementation (preliminary version is scheduled for late 1978 pending continued funding), FORPLAN will give the manager access to virtually all the models, simulators and data bases described above. To illustrate FORPLAN's ease of use, consider:

A manager has data consisting of stand age, slope and tree density tables. He wants to simulate what would happen if he thinned his forest now, and has a fire (under his 80th percentile cumulative weather conditions) 10 years from now. He needs to know the effects on vegetation, ungulate populations and timber, and the costs of the fire on his potential timber harvest. Currently, this information is available to the manager for selected areas; however, he must consult five different data bases located on three different computers, and then massage these data through eight different models.

Alternatively, FORPLAN can consolidate all of this information on a single system, select and interface the required models and data bases, and allow the manager to conduct the entire simulation with the 13-line FORPLAN program:

```
GET DATA
BUILD FOREST
TIME 0
THIN FOREST
TIME 10
GET WEATHER, 80 %
DISTURB FIRE
STATISTICS
EFFECT VEGETATION
EFFECT UNGULATES
HARVEST TIMBER
COST
END
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FORPLAN is an entirely new concept in fire management. While it does not pretend to be a replacement for good communication between researchers and managers, it certainly has the potential of reducing the difficulty encountered when managers attempt to use fire management models and systems.

We cordially invite comments from researchers and potential users on the proposed system's general utility and especially its applicability to fire-prone Mediterranean ecosystems.

ACKNOWLEDGMENTS

We thank Tim Paysen, Gene Conrad, Gay Almquist, Randy van Gelder and Richard Chase for their comments and suggestions during the development of the FBIIS. Considerable photo interpretation and imagery work was conducted by Jesse Grunblatt, Gradient Modeling, Inc. This research was supported by cooperative agreements between the USDA Forest Service and Gradient Modeling, Inc.

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FOSSIL CHARCOAL AS A MEASURE OF WILDFIRE FREQUENCY IN SOUTHERN CALIFORNIA: A PRELIMINARY ANALYSIS[1]

By

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Abstract: Sections of two varved cores from the Santa Barbara Channel were analysed for their fossil charcoal content. The first covers the period 1931-1970 and contains a charcoal record that is primarily a reflection of large fires in the southern part of the Los Padres National Forest. The chronology of the second core is still "floating" but we estimate that the samples analysed represent ca. 150 years from the 16th and 17th centuries. This record contains evidence of two major fire/flood events and also suggests that large fires occurred every 20-30-40 years following relatively quiet low fire periods.

Key words: Fossil charcoal, Santa Barbara varved sediments, Los Padres National Forest, fire history.

INTRODUCTION

The ecological significance of fire in southern California is now widely recognised although not very long ago this was not the case. Most foresters and botanists regarded fire as an unnecessary evil and fire prevention was the rule (Biswell 1967; Vogel 1967). One unforseen consequence of fire prevention has been the "unnatural" accumulation of fuel, which in turn has created fire regimes that are in many ways undesirable (Dodge 1972). Large hot fires, conflagration fires as they have been called, have occurred with increasing frequency and have been responsible for an increasing proportion of the total acreage burned. This has meant that plants and animals adapted to more frequent but less intense fires have become rare and in some cases are threatened with extinction (Minnich 1974). Human life and property have also been endangered. In 1970 16 people died as a result of California wildfires, and damage and suppression costs for that year have been estimated at $233,000,000 (Countryman 1974). The undesirable consequences of complete fire prevention are now well recognized and a reassessment of earlier policies is currently under way. Unfortunately, there is still a great deal of uncertainty as to what the natural frequency, or frequencies, should be.

This uncertainty is well illustrated by the debate as to the ecological significance of California's prehistoric Indian population. Some authorities have argued that prehistoric Indians frequently burned extensive areas of southern California, particularly the Oak/Grassland Savanna and Chaparral (Aschmann 1974; Lewis 1973). Others have suggested that the prehistoric Indian population was too small to have had anything more than very local effects (Burcham 1974). The controversy is reminiscent of the Angel/Pin problem. The evidence is lacking and one's point of view is largely a matter of faith.

In this paper we draw attention to an unusual fossil record that should eventually provide the best estimate of prehistoric fire frequencies in the Coast Ranges of southern

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California. More specifically, we report on a preliminary analysis of the fossil charcoal content of sections of two varved cores from the Santa Barbara Channel.

The first core was a short box core which had a total length of 40 cm. and covered approximately the last 150 years. Of this we have analysed 40 individual varves representing the period 1931-1970. The objective here was to calibrate the fossil charcoal record against fire history data from the National Forests. The second core was a 13.4 m. long piston core of which the upper 6 meters was varved. These varves probably represent the last 5,000 years. To date we have analysed 30 composite sample representing a total time period of 150 years. The chronology of this core is still "floating", but we estimate that the samples analysed date to the 16th and 17th centuries. They definitely predate the period of European settlement.

THE SANTA BARBARA VARVES

Halfway between the northern Channel Islands and the California coast is the Santa Barbara Basin, a submarine basin with a basal depth of ca. 590 meters below sea level. The sediments that accumulate in this basin are unusual insofar as they are varved.

Varves are rarely encountered in marine sediments because of disturbance by bottom-dwelling organisms. In the Santa Barbara Basin, however, the bottom waters contain very little dissolved oxygen and the bottom fauna is therefore impoverished (Hülsemann and Emery 1961). This in turn means that seasonal differences in sediment type are preserved as varves. Each varve consists of two layers or laminations. The winter laminae are usually pale green in color and consist largely of inorganic clay and silt-sized particles. These sediments are terrestial in origin and are washed into the ocean during winter storms. The summer layers are lighter in color and consist primarily of organic material - diatoms, foraminifera, and radiolarians. The summer and winter layers differ in density and therefore can be readily identified by radiography (fig. 1).

Varved sediments such as these offer many advantages for paleoecological research. They permit the establishment of an accurate absolute chronology and also allow for the calculation of absolute influx values. Cores from the Santa Barbara Channel have already provided useful information on such diverse problems as sardine history (Soutar and Isaacs 1974), mercury pollution (Young et al. 1973), isotope dating (Koide et al. 1973), and climatic change (Soutar and Crill, in press).

Figure 1--A contact print of an X-radiograph of a section of core P2. The scale indicates depth below core top in centimeters. The light layers are the less dense summer layers. The dark layer at the top is one of the dense "grey layers" discussed later in the text.

The present study was prompted by Griffin and Goldberg's (1975) analysis of elemental carbon in Santa Barbara varved sediments. Using a short core similar to the one used in this study, they determined percent weight elemental carbon by infra-red spectroscopy for 25 composite samples covering the period 1825-1970. Their results indicated a slight increase in elemental carbon over the past century, but the increase was not clearly related to any fire history record. They concluded, therefore, that forest and brush fire control had had little effect on the flux of elemental carbon in the Santa Barbara Channel. One problem in their analysis was that carbon produced by wildfires and elemental carbon produced by fossil fuel combustion can not be distinguished by infra-red spectroscopy. In order to try and resolve this problem and hopefully to establish a closer connection with fire history data we analysed another short core from the Santa Barbara Channel, but used a different sampling interval and different methods of analysis.

METHODS

The short core (core 262) was collected in September 1971 from the Santa Barbara Basin (34° 14' N, 119° 59' W) at a water depth of 592 meters. It was recovered by the use of a specially designed coring device which minimizes disturbance of the sediments (Soutar *et al.* 1976). The recovered core measured 20 x 20 x 40 cm. Immediately after collection it was frozen and preserved at -20°C. The core was sliced into 1.5 by 18 cm. sections and each section radiographed. The radiography showed clearly distinct varves for the period 1931-1970 but below that the chronology was complicated by a non-varved layer. We therefore limited our analysis to the period 1931-1970. A frozen core section was allowed to thaw and each annual couplet carefully sectioned. Varve thickness during this time period ranges from a maximum of 10.5 mm. to a minimum of 2.0 mm. Differences in varve thickness are in part a function of variable water content and also reflect changes in sediment influx. These variables do not affect charcoal influx values, which are calculated according to the surface area of the sample, i.e. charcoal influx per $cm.^2$/per year

The long core (core P2) was collected in March 1976 from a location 1 nautical mile south of the short core site (34° 13' N 119° 59' W). The water depth at this point is 571 meters. The recovered core was 13.4 meters long probably representing a period of at least 12,000 years of which the last 5,000 years are varved.

This core (8 cm. diam.) contained a smaller volume of sediment per unit time than the short core and the samples used were therefore also smaller. After the core was extruded, constant volume samples measuring 4.0 cm. x 0.5 cm x 0.75 cm, were taken for charcoal analysis. Each sample represents approximately 5 years of sediment accumulation. The exact period of time included in each sample can be determined from radiographs taken prior to the final sampling. Calendar dates will eventually be established, but at this stage we simply number the samples according to depth. A preliminary comparison with dated varved cores from the Santa Barbara Channel suggests that the samples included in the present study date to the 16th and 17th centuries.

In extracting the charcoal we used techniques developed by Waddington (1969), Stockmarr (1971), and Swain (1973). As a means of estimating absolute influx values, a known quantity of Lycopodium spores was added to each sample prior to processing. In order to concentrate the charcoal into countable amounts, each sample was subjected to the following treatments: HCI (10 percent) 5 minutes, KOH (10 percent) 5 minutes, 8 to 10 washes with distilled water and short centrifuging (1 minute at 2,000 rev. per minute) to remove colloidal material, HF (conc.) for 24 hours, HNO_3 (conc.) cold for 4 minutes, Acetolysis. This extraction procedure is basically similar to that used in concentrating pollen from Quaternary sediments (Faegri and Iverson 1975). The resulting concentrate, which is rich in both pollen and charcoal, was mounted in silicone oil (2,000 centistokes) on standard microscope slides. Charcoal counts were made by estimating the "area" of charcoal traversed while counting a set total of Lycopodium spores. The sizes of individual charcoal fragments was recorded with the aid of an eyepiece graticule containing 25μ x 25μ squares. Only charcoal exhibiting obvious cellular structure was included in the counts. Several "types" of charcoal were encountered in the analysis (fig. 2). At this stage, however, we did not make any taxonomic distinctions in the counts.

Figure 2--Photomicrographs of fossil charcoal from the Santa Barbara varved sediments. The upper fragment is grass epidermis, note the stomatal cell. This fragment is 85μ long. The lower fragment is as yet unidentified.

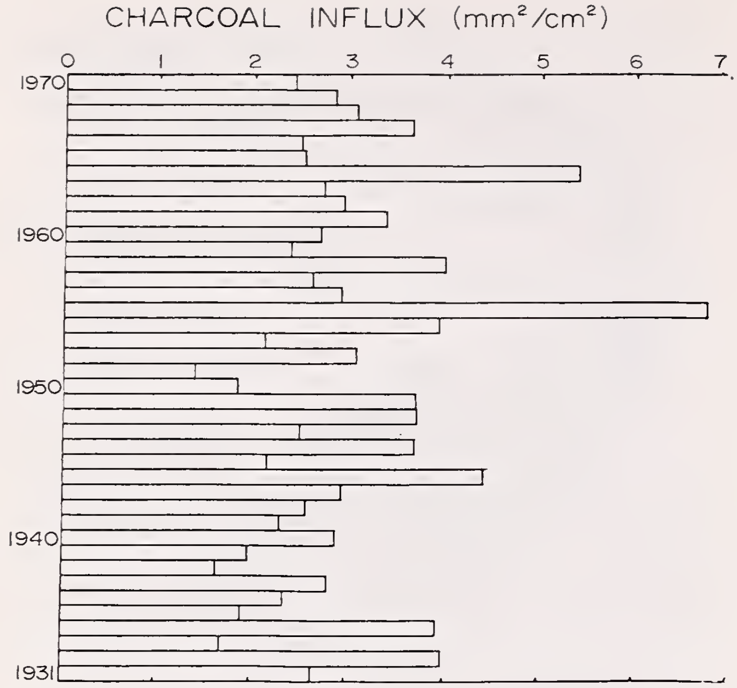

Figure 3--Charcoal influx values for core 262.

THE CHARCOAL/WILDFIRE CALIBRATION

The charcoal counts for the short core samples are given in figure 3. Initially we attempted to cross correlate them with published wildfire data for the four National Forests in southern California: Los Padres, Angeles, San Bernadino and Cleveland. However, the resulting correlation coefficients were all low, indicating that the charcoal record was not recording fire history at this level of generalization.

Fortunately, we were later able to obtain unpublished fire history data for Los Padres National Forest, which were tabulated on a ranger district basis (fig. 4), and on this scale a much more coherant pattern emerged.[1] It became clear that the major peaks in the charcoal record were the result of large fires that had occurred on the first coast range (Santa Ynez Mountains) at a distance of less

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[1]Unpublished fire history data were kindly provided by H.B. Cahill of the U.S. Forest Service Office, Santa Barbara.

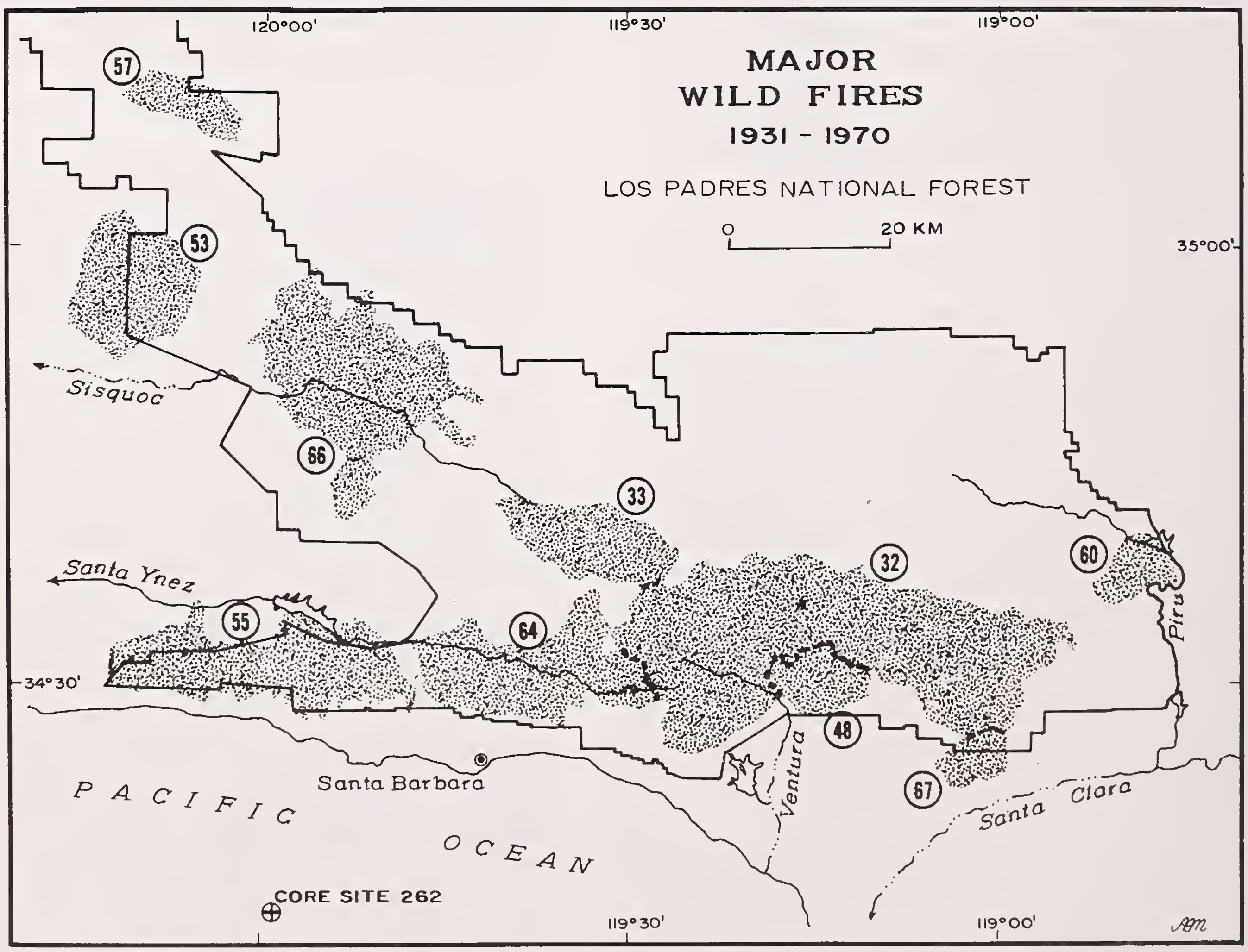

Figure 4--Major wildfires in the southern section of the Los Padres National Forest 1931-1970. The circled numbers indicate the year in which the fire occurred.

than 50 km. from the core site, as for example in 1955 and 1964. Large fires in areas behind the first coast range, or in areas more than 50 km. to the east, did not "appear" in the charcoal record for the same year but seemed to be responsible for peaks in the following year. This lag effect is well shown by the large fire of 1966 that presumably was responsible for the high charcoal count in 1967. It is also clear that large fires remote from the core site do not have a major effect on the charcoal influx. In 1942, for example, over 40,000 acres were burned in the Monterey Ranger District and adjacent areas, at an approximate distance of 250 km. from the core site. However, in both 1942 and 1943 charcoal influx values were below average.

On the basis of an initial inspection of the data, we conclude that wind was probably the primary transport mechanism for charcoal from local fires whereas run off and subsequent transport by ocean currents were responsible for transporting charcoal from fires occurring more than 50 km. from the core site. In either case, there is clearly a strong distance effect which results in more charcoal reaching the core site from local fires than from remote fires, per unit area burned.

In order to establish the charcoal/fire relationship more precisely, and as a preliminary step to the development predictive equations, we subjected the data to an analysis of variance.

More specifically, we divided the influx values into three classes on the basis of the fire history. Class one contained values for years having fires of more than 1000 acres with some portion of the fire extending onto the coastal side of the Santa Ynez Range. The second class contained influx values one year later than fires of more than 10,000 acres in the more remote sections of Los Padres National Forest. This included most of Ventura County and Santa Barbara County north of the Santa Ynez Range. Fires in San Luis Obispo and Monterey Counties seemed to have no noticeable effect on charcoal values and were not included in the analysis. Class three contained influx values for the remaining years.

The mean influx level for all years was 2.97 mm^2/cm^2. The mean values for the three classes was respectively, 3.99 mm^2/cm^2, 3.35 mm^2/cm^2, and 2.48 mm^2/cm^2. The null hypothesis that there was no difference between the classes was tested on a Fisher's F-test with 2 and 37 degrees of freedom. The f-ratio of 10.58 was significant at the .001 level, allowing the null hypothesis to be rejected. The three most obvious and important conclusions to be drawn from this part of the study are:

1. The Santa Barbara Charcoal record is particularly sensitive to large fires occurring at a distance of less than 50 km from the core site.

2. Large fires occurring between 50 and 100 km from the core site are visible in the record but the response is not as clear.

3. Large fires occurring at a distance of more than 100 km from the core site do not appear to have a significant effect on charcoal accumulation rates in the Santa Barbara Channel.

These conclusions are clearly tentative and may be modified by further research. However, on the basis of the available evidence they appear to be valid.

THE LONGER TERM RECORD

The charcoal influx values for the 16th and 17th centuries are given in fig. 5. Unlike the short core, each sample represents a constant volume which on average represent a period of fire years. As a means of comparison, therefore, we have also included five year average values from the short core.

The most prominent features of the pre-European record are the extremely high values at levels 340-355 and 455-60. The actual influx values are not plotted on the graph but are higher than the average value by a factor of at least ten. These layers are grey and correspond with very dense layers on the radiograph and presumably represent major fire-flood events. Similar layers are commonly encountered in cores from the Santa Barbara Channel and have been variously interpreted as turbidite deposits (Hülsemann and Emery 1961), and winter flood deposits (Drake <u>et al</u>. 1971). The high charcoal content suggests the latter interpretation is more nearly correct.

Apart from the grey layers, the average influx value for the prehistoric period is somewhat lower than for the modern period: 1.77 $mm^2/cm^2/yr$. as compared with 2.97 $mm^2/cm^2/yr$. This tends to confirm Griffin and Goldberg's (1975) findings that the elemental carbon flux into the Santa Barbara Channel had increased slightly during the present century. It is probably not of function differences in core site location because the long core (P2) was taken further from the coastline than the short core. The implication is that total burning was greater during the period 1931-1970 than in the prehistoric period sampled.

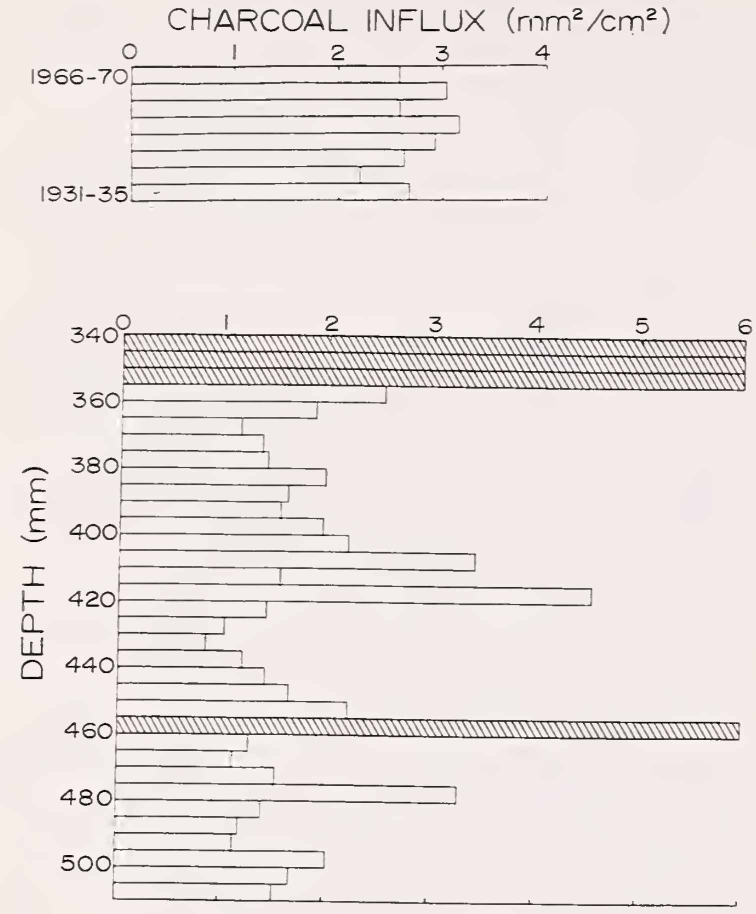

Figure 5--The upper graph gives 5-year average values for the core 262. The lower graph gives influx values for core P2. The diagonally shaded levels are the dense "grey layers" discussed in the text. Their charcoal content is extremely high and is not plotted on this graph.

Perhaps the most unexpected feature of the prehistoric record is the high inter-level variance. In comparison the modern values are much more complacent. The difference here could be in part a statistical artifact, a result of smaller samples for the prehistoric period. It is unlikely, however, that all of the variance could be explained in this way.

The record implies that there were quiet periods of 20-30-40 years during which few fires occurred in the adjacent Coast Ranges. These quiet periods were then followed by major fire and flood events. Paradoxically, the fire frequency regime of the modern protection period may be more "natural" than has commonly been recognised!

SUMMARY AND CONCLUSIONS

The charcoal content of a varved short core from the Santa Barbara Channel was analysed for the period 1931-1970. The influx values were then compared with fire history data from the National Forests and it became apparent that the record was primarily a reflection of major fires in the southern part of the Los Padres National Forest.

A preliminary analysis was then made of a varved long core which had been collected in the same area as the short core. The results indicate that during a period of ca. 150 years in the 16th and 17 th centuries at least two major fire-flood events occurred. However, if these samples are excluded, the average influx values for the pre-European period is lower than for the modern period, suggesting that there was less net burning per unit area, per unit time. On the other hand inter-sample variation is higher in the pre-European period than in the modern period, indicating that large fires may have occurred every 20-30-40 years following relatively less quiet periods.

We must emphasise that these results are only preliminary ones, obviously a great deal remains to be done. For example, the charcoal transport mechanisms are still poorly understood. What is more important water or wind? How far, and in what quantity, can charcoal be washed or blown from a fire of known size? What different kinds of charcoal are encountered in these sediments? Questions such as these must be answered if the Santa Barbara charcoal record is to be interpreted intelligently. As we indicated earlier, at least 5,000 years of varved sediments are currently available for analysis. Furthermore, similar varved sediments of Tertiary age are locally common in southern California (Bramlette 1946). Theoretically the record could be extended back for millions of years

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ACKNOWLEDGMENTS

We would like to thank Robert Mangold for his help in the earlier stages of the study, Adrienne Morgan for drafting and Natalia Vonnegut for typing.

ANIMAL RESPONSES TO FIRE AND FUEL MANAGEMENT IN CHAPARRAL[1]

Harvey B. Lillywhite[2]

Abstract: Burning of chaparral periodically rejuvenates the community and perpetuates complexity in spatial dimensions. Where chaparral exists as a mosaic of seral vegetation, the community has a higher productivity, higher diversity, and a greater carrying capacity for consumer organisms. Controlled burning for the purpose of managing fuels can therefore benefit wildlife provided that the burning schedule maintains diversity and productivity of the chaparral. Alternatively, the replacement of chaparral with grasses (type conversion) lowers diversity and results in net losses of resources and resource exploitation possibilities. Examination of existing grass conversions indicates that the vertebrate fauna is impoverished compared with wild chaparral.

Key words: Chaparral, fire, fuel management, wildlife habitat, species diversity, vertebrates.

INTRODUCTION

Animals are an important element of the chaparral ecosystem, and knowledge of their responses to changes in this ecosystem is an important contribution to our understanding of the area's ecology. To manage shrublands for maximum values, we need to know about the interrelationships of plants and animals in the ecological change which follows vegetation manipulation.

Fire has presumably always been an important forcing function in the evolution of chaparral biota. Many of the floral elements possess climatic-induced features which encourage fire and, in a reciprocal relationship, depend on recurrent fires for optimal growth and vigor (Biswell 1974; Hanes 1971; Mooney and Parsons 1973). Animals, too, are adapted to withstand the effects of fire and may even flourish under conditions of postfire succession.

Much less is known ecologically about the potential or realized consequences of management schemes which seek to manipulate the floristic structure and composition of chaparral and other shrubland communities. This paper discusses animal responses to fire and fuel management in the chaparral of California. Such insights as can be gleaned from a presently meager literature are at a premium in view of accelerating efforts to alter the floristic structure of native, wild plant assemblages.

FIRE'S DIRECT EFFECTS

Brush fires burn rapidly and intensely (temperatures may exceed 700 °C in chaparral) depending on terrain, vegetation structure, and weather conditions. Carcasses of charred or asphyxiated animals are occasionally evident on burns, but a majority of studies indicate that direct mortality from fire is small or insignificant in chaparral (Howard et al. 1959; Kahn 1960; Lawrence 1966) and in other communities (Komarek 1969; Vogl 1973 and references therein). Animals can escape the lethal effects of fire by selecting insulated microenvironments or by emigrating from the area. As a result, fire usually disturbs populations less

[1] Presented at the Symposium on Environmental Consequences of Fire and Fuel Management in Mediterranean Ecosystems, Palo Alto, Calif. Aug. 1-5, 1977.

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profoundly by its direct action than by changing the habitat.

POSTFIRE CHANGES IN ANIMAL COMMUNITIES

Animal communities exist in a dynamic steady state in which spatial and temporal patterns of structure are functions of the range and variation of resources. This fact relates to the fire ecology of animals in basically three ways. 1) Resource gradients and habitat heterogeneity are changed by fire. 2) These factors secondarily induce changes in animal abundance and diversity. 3) While local populations may temporarily change or shift along a resource gradient, the aggregate abundance, diversity, and (probably) stability of populations over a broad geographic area are maximized by the effects of periodic fire.

Habitat Changes

Fire dramatically and abruptly changes the configuration of an animal's habitat by removing all of the existing vegetation and accumulated litter. This reduces microhabitat diversity and produces a very open, simplified environment. After these early effects, however, there occurs a vigorous recovery of the woody vegetation and an appearance of great numbers of annuals and short-lived perennials (Biswell 1974). The open, simplified aspect of the burned environment is relatively short-lived, and within 2-5 years the flora develops to a state of maximum luxuriance. In its rejuvenated state, the community has a higher productivity, higher diversity, and a greater carrying capacity for consumer organisms (Mooney and Parsons 1973).

After about 10-14 years the community gradually regains its former physiognomy and species composition. As the chaparral ages to maturity (20-50 years), floristic richness decreases, the production of new growth slows down, and the herbaceous ground cover becomes almost nonexistent. Closure of the canopy restricts resources and imposes constraints on resource exploitation possibilities. As a note of clarification, "resource" here refers to all physical and biotic attributes of the environment relevant to animal niche dimensions.

Animal Abundance and Diversity

Faunal communities in chaparral are conspicuously structured on the basis of vegetation. Thus, disturbance of the vegetation structure inevitably influences the integrated organization of the associated fauna. In the aftermath of a fire there usually but not necessarily ensue changes in the relative densities of animal species. These changes are generally reversed with the floristic succession of the community.

During the rather immediate postfire period, the numerical and/or behavioral density per species may decline due to the singular or combined effects of direct mortality, egress, predation, or altered activity patterns. Attention to this latter factor is instructive, for resident small mammals surviving a fire may appear to be temporarily absent from the habitat owing to a reduction of surface activity during the exposure of surface runways (Lawrence 1966). Small mammal trapping in burned habitat is frequently most successful near protected sites (Lawrence 1966; Lillywhite, unpublished). Other organisms surviving fire _in situ_ may experience little numerical change (ants, for example), while still others increase in density owing to what might be termed "opportunistic" habitat selection. Various insects and vertebrates are attracted to the smoke or heat of fire, and many animals concentrate activities (grazing, browsing, hunting) in freshly burned habitat (Evans 1971; Komarek 1969; Lawrence 1966; Stoddard 1963). Ingress may add new species, and predation may assume a determining role in restructuring a community.

Following the immediate shifts in animal density and composition, there ensues a variable but relatively brief period of population growth which crudely parallels the resource diversification alluded to earlier. That is, recovering populations may increase rapidly to prefire levels or, more frequently, achieve higher densities than characteristic of climax habitat. An example for chaparral lizards is illustrated in figure 1 which is discussed below in relation to management. Two other examples will suffice to generalize the point.

The responses of deer populations to burning have been studied quantitatively in the chaparral regions of northern California. In comparison with dense habitat, recently burned chaparral supports greater numbers of deer in populations characterized by heavier animals and higher reproductive rates (reviewed in Biswell 1961). The improvement of game production in burned habitat is usually attributed to habitat heterogeneity and to an increased availability and diversity of palatable, high-nutrient browse (Bissell et al. 1955; Biswell and Gilman 1961; Dassman et al. 1967; Gibbens and Schultz 1963). These aspects of game management seem to be generally appreciated by sportsmen and ranchers familiar with the chaparral ecosystem (Hendricks 1968; F. R. Garnsey, personal communication).

Smaller vertebrates have been studied comprehensively following controlled burning in the Sierra Nevada foothills (Lawrence 1966). Population estimates from this study are probably most accurate for birds. The fire resulted in an overall increase in the densities of nesting birds within the first year following the fire, an effect that was attributed to the availability of seeds and insects near the ground surface. By the third year after the fire the total number of birds apparently stabilized at preburn densities, although the species composition had shifted (as had that for rodents). Birds that normally prefer grassland or oak woodland increased in number while the chaparral species were reduced. These data agree with the findings of others and permit generalization: species shifts in postburn habitat parallel closely the nature of the vegetation (Beck and Vogl 1972; Bock and Lynch 1970; Cook 1959). There is frequently a tendency toward a slightly richer fauna (more species) in burned habitats (see review by Bendell 1974).

Increases in population and/or species densities following fire is no doubt related to the increased productivity of the habitat and to environmental patchiness in three dimensions, leading to new possibilities of differential resource exploitation. Total aggregate energy flow is probably increased after burning, but more detailed and quantitative studies are presently needed to elucidate this point (see Bock and Lynch 1970).

Patterns in Time and Space

When subject to natural burning cycles, chaparral exists as a mosaic of seral vegetation. The added resource complexity attributable to this patchiness is important to animals whose requirements include food (browse, seeds, insects, etc.), cover (relatively dense brush), basking or sentry sites (openings), and any number of other microhabitat features. Fire generates temporal and spatial diversity in a potentially more homogeneous ecosystem (e.g. chamise climax), and under these conditions habitat productivity and aggregate biotic density and diversity will be maximized. Much of this diversity is lost, however, when an extensive area of mature chaparral assumes a closed canopy composed of relatively few (sometimes one) shrub species.

WILDLIFE AND FUEL MANAGEMENT

Because of urbanization and the encroachment of human activity onto the chaparral lands of California, brush fires are a vital public concern. In recent historic times, fire suppression policies, assiduously practiced in southern California, have augmented fuel accumulations in brush fields and have thereby enhanced conditions which favor inevitable catastrophic wildfire. Largely because of this fact, fire control policies are controversial (Hanes 1971; Parsons 1976). On the other side, if natural or prescribed burning were periodically allowed, fire would be restored to a more natural role, and the chaparral landscape would again assume a mosaic of floral configurations. This patchiness, together with topographic features, would create natural fuel breaks restricting the size (and intensity) of future fires which, in turn, would perpetuate the habitat mosaic. The reader now realizes that this approach to fuel reduction is entirely compatible with the aims of game management and wildlife preservation. Wildlife considerations have, in fact, provided impetus for the acceptance and implementation of controlled burning in California.

Controlled Burning

From an animal ecology viewpoint, the benefit of controlled burning can substitute for that of natural fire cycles provided that the fire schedule maintains diversity and productivity of the chaparral. Thus, in the North Coast Ranges of California controlled burning enhanced significantly the productivity of chaparral for deer and other non-game vertebrates (Biswell 1961). It is crucial to note, however, that burning schedules were structured such that chaparral succession was temporarily reversed in spatially heterogeneous patterns. This resulted in habitat patchiness in addition to browse and forage availability, but the chaparral flora was not eliminated. If a burning schedule is indiscriminate, however, the effects of fuel reduction projects on wildlife can clearly be negative. For example, burning too frequently can reduce plant species richness, eliminate valuable browse species, and degrade the habitat.

Grass Conversions

At present chaparral wildlands in California are being modified at accelerating rate (e.g. US Forest Service 1972). Shrub cover is being reduced or eliminated by mechanical clearing, burning or chemical suppression, and exotic grasses have been introduced as replacements for native species. Much of these efforts are directed at converting the cover type as an adjutant in suppressing fire. Unfortunately, there has been little attempt to assess the effects of such ecological modifications on

either the chaparral fauna or the chaparral ecosystem generally.

Mediterranean climate ecosystems hold rich faunas (di Castri 1973; Cody 1974), evolutionarily attributable (in part) to the structural complexity of the habitat. The role of spatial heterogeneity in regulating community diversity has received much attention from ecologists, and it seems a truism that vegetation structure provides a major component of natural selection for animal community organization. Empirically, species diversity has been shown to co-vary with indices of vegetation complexity which are nearly always higher for shrubby habitats than for grassland (Roth 1976 and references therein). One should expect that, all other things being equal, the greater the habitat heterogeneity in terms of plant structure and composition, the greater the numbers of kinds of animals. This principal can be seen to apply both in the evolutionary development of a community and in cases of manipulating habitats on a shorter time scale. I next discuss some recent empirical support for this statement.

Using short-term sampling methods, I have determined relative population densities of small vertebrates on sites of chaparral and chaparral-grass conversions in southern California (Lillywhite 1977). Sampling was relatively most thorough for lizards which are rendered conspicuous by diurnal habits and are abundant and easily studied. Moreover, these vertebrates may be particularly sensitive ecological "indicators" because of their limited vagility. As a result, habitat modifications have an important influence on their abundance and distribution.

As indicated in figure 1, lizard abundance is highest in relatively sparse chaparral (opened by burning) and decreases either up- or downscale on the habitat gradient (percent shrub cover). While the total abundance of lizards decreases in dense shrub habitat relative to postburn habitat, the density of species stays constant. I emphasize, however, that lizards are virtually absent from grass habitats not having any shrub cover. When the data for the various sites are grouped according to whether shrubs are present or absent from the habitat, both species diversity (H') and total density of lizards (average number of lizards per trap station) are statistically significantly higher in the former habitat ($P < 0.001$). Similar trends were evident for small mammals: a total of eight species was taken in shrub habitats while only one species was taken on the grass sites devoid of shrub cover. Data from an

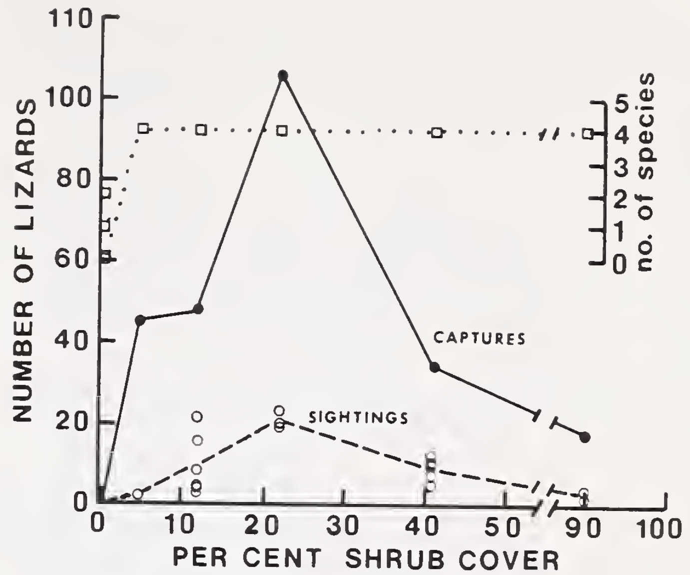

Figure 1--The effect of shrub density (measured as the percentage of ground covered by the perpendicular projection of shrubs) on the number of species and total abundance of lizards in a series of habitats near San Diego. Sampling sites included dense chaparral, postburn chaparral, and areas of total grass conversion (57-200 ha). Each data point represents a cumulative total for live trapping (840 trap-days using pitfalls: Lillywhite 1977) or for sightings of lizards during one-time census walks over 0.5 ha plots.

independent study conducted elsewhere in the Cleveland National Forest are also complementary: in a series of habitats, burned chaparral yielded the highest density and greatest species diversity of rodents, while large grasslands showed the lowest (Bell and Studinski 1972).

Clearly, eliminating the shrubs from chaparral eliminates certain of the animal inhabitants. Similarly, shrub eradication in Great Basin sagebrush and in Texas brushland impoverishes populations of animals variously dependent on a woody vegetation (Davis and Winkler 1968; Vale 1974). Similar community responses can be expected in spatially distant and independently evolved ecosystems having parallel organization and structure. In the Mediterranean-climate communities of Chile, even the soil fauna is known to be structured on the basis of vegetation, and species diversity decreases in manipulated habitats (di Castri 1973).

With respect to fuel management compatible with wildlife interests, this paper argues for manipulation rather than conversion of wild vegetation in chaparral. While some minimum

interspersion of grass openings with shrubby habitat may seem initially desirable, schemes which encourage the conversion to grass of large areas of chaparral disregard relatively sedentary animals having small home ranges and little or no ecological adaptation to a grass habitat. These species will become increasingly restricted to smaller and more isolated patches of chaparral if grass conversion becomes extensive. By analogy with models of insular biogeography (see Diamond 1975), the number of species which a given patch of chaparral can hold is a function of its size and isolation. Thus, as more and more area of chaparral is converted by man into another habitat, some estimable number of chaparral species will eventually disappear. Patchiness in seral chaparral offers a richer mosaic than the "either-or" situation of grass conversions, and larger areas with greater habitat heterogeneity can produce higher species counts.

The diversity of species in chaparral probably mediates some functional stability in the community (McNaughton 1977), a quality that is frequently diminished when a well coevolved system is replaced with a small number of introduced, alien species (Pimentel 1970).

ACKNOWLEDGMENTS

My field work in California was facilitated by the interest of the USDA Forest Service, Descanso Ranger District, and by financial assistance from the American Philosophical Society (Penrose Fund grant 7054), Biomedical Sciences Support Grant RR-07037, and the University of Kansas.

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CHAPARRAL SOILS AND FIRE-VEGETATION INTERACTIONS[1]

Marvin Dodge[2]

Abstract: Soil-vegetation surveys and information on soil developement processes were used to evaluate chaparral-covered areas in Southern California. Evolutionary history of chaparral was combined with ecological relations between chaparral and grasslands and woodland-grass to examine alternatives for management of wildland areas. Dense stands of chaparral were found occupying grassland and woodland-grass soils, with serious erosion and soil degradation taking place, especially following high-intensity wildfires in the chaparral. Restoring the natural vegetation could reduce fire hazard and soil erosion losses.

Key words: Soils, chaparral, fire, erosion, grasslands, prescribed burning.

Many conflagrations have raged through the California chaparral destroying homes and property and frequently causing deaths. Floods resulting from rainfall upon fire-denuded slopes have probably caused as much property damage as was done by the fires themselves. As a result; many studies have been made of the chaparral vegetation, but relatively little attention has been given to the soils.

Chaparral is a plant community composed of sclerophyllous shrubs - evergreen plants with stiff branches and, generally, thick leathery leaves, often with a waxy cuticle. It is a typical Mediterranean vegetation type growing in a climate with cool, rainy winters and warm to hot, dry summers. The shrubs of the chaparral areas are widely recognized as a fire-type formation (Clements 1922; Jepson 1923). Some ecologists believe fire is nécessary to preserve the chaparral of Southern California since many component species require fire for their reproduction and survival (Hanes 1971).

The most thorough paleobotanical work upon the development and evolution of the chaparral vegetation has been done by Axelrod. He concluded that it evolved in a number of small localized areas of relatively arid conditions from the more tropical plants covering much of Central America and the southern United States during the Tertiary Period, probably upon edaphic drought areas (Axelrod 1958, 1972). Many individuals of the various chaparral species probably occurred as scattered understory plants in the forested areas (Axelrod 1975). Recent studies on soils and vegetation in Southern California have shown that, at the time of the white man's arrival, scattered individuals and tiny pockets of chaparral species were very wide spread, but there were comparatively few large, dense stands of chaparral (Dodge 1975).

Early ecological studies of chaparral said little or nothing of the soils upon which it occurred (Plummer 1911; Cooper 1922).

What was perhaps the earliest description of chaparral soils described them as shallow, rocky soils with low moisture-holding capacity (Sampson 1944). Later descriptions agreed and pointed out the very low fertility levels of primary chaparral soils made it difficult

1/ Presented at the Symposium on Environmental Consequences of Fire and Fuel Management in Mediterranean Ecosystems, Palo Alto, Calif. Aug. 1-5, 1977.

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or impossible to grow forage grasses or other types of vegetation upon chaparral sites (Hellmers, Bonner, and Kelleher 1955; Burcham 1957).

The development of a soil is a function of the parent material, slope, climate, and vegetation operating overtime (Jenny 1941). Level and gently sloping terrains have a slower runoff from precipitation and provide more time for infiltration than steeper slopes. As a consequence, chemical weathering extends over a longer time and to greater depths on gentle slopes than on steep hillsides. Steeper slopes impart greater velocity to both surface runoff and subsurface drainage increasing the ability of water to remove soil particles. The combination of less weathering and greater erosion potential on steep slopes generally produces shallow, coarse soils as compared to deeper, finer-textured soils that develop upon gentler slopes.

Vegetation and soils interact with each other within the broad limits determined by climate (Eyre 1968). The dense, fibrous roots of grasses are very efficient at intercepting and recycling any downward percolating nutrients. This dense network of roots also helps retain the finer soil particles. Grassland soils are characterized by their high clay content and good fertility (Buckman and Brady 1960). Forest trees are also quite efficient at intercepting and recycling nutrients percolating downward through the soil profile (Lutz and Chandler 1946). The organic matter added to the soil as litter and humus is very effective at preventing erosion.

Most chaparral species, on the other hand, have a very deep root system, often exceeding 35 feet in depth (Hellmers, Horton, Juhren and O'Keefe 1955). There are relatively few lateral roots near the surface and almost no fibrous roots to hold surface soil particles. There frequently is little or no litter and organic matter beneath stands of chaparral, particularly chamise (Adenostoma fasciculatum). Consequently, soils under a chaparral cover erode readily and lose the nutrients and finer-sized soil particles rather quickly, leading to shallow, coarse-textured soils with low water-holding capacity and low fertility.

Laboratory analyses made as part of the California Cooperative Soil-Vegetation Survey confirm the low-fertility of the chaparral soils. Although not all of the primary chaparral soils have had detailed analysis, those that have been run through the laboratory all show low-fertility levels.

It should be pointed out that a soil series is an artificial classification, devised by man. It is superimposed upon a natural system composed of many factors interacting with each other. The soils developed by nature have a wide range of characteristics intergrading imperceptibly from one to another. Nature's array of soils do not conveniently fit into the classification pigeonholes. Likewise, soil surveys have practical limitations. Limits on manpower and funds mean compromises must be made on the size of soil units surveyed and mapped. The State Cooperative Soil-Vegetation Survey mapped slightly contrasting soil types down to a 40-acre minimum. Strongly contrasting soil types that might need different management techniques are mapped to a 10-acre minimum. Wildland soils, found in rough, broken terrain seldom present 10 acres of uniform slope, so we find nearly all mapped soil units have many areas of other soil series included. There might be many small areas of swales and gentle slopes where erosion operates at a slower rate, so the soils are deeper and better developed than in the surrounding area. There are also many small areas of much steeper slopes, such as the edges of gullies and canyons, where soils are very shallow and coarser in texture than the average of the area or mapping unit. Such numerous, but tiny, ecological niches, many of them no more than 5 to 10 square meters in size, provide edaphic sites for the chaparral species among the forest, woodland and grassland areas (Dodge 1975). Since many of these ecological niches occurred upon steep ground with unfavorable conditions for herbaceous vegetation, they also served to protect the chaparral from frequent, low-intensity surface fires as there is little or no fine dead fuel on the ground to carry fire.

Many of the chaparral species are very adaptable and aggressive. They readily invade soil types normally occupied by other vegetative communities if plant competition is greatly reduced. The invasions are more successful and persistent if the soils are degraded by erosion and severe disturbance such as heavy overgrazing on grasslands and poor logging practices on timberland soils. The reduced water-holding capacity, loss of nutrients, reduction of organic matter, and higher soil temperatures favor the chaparral species and make conditions more adverse for either grasses or trees. Likewise, high-intensity fires on areas invaded by chaparral may cause further erosion and degradation of soils, increasing the probability that chaparral will continue to dominate the site.

Contrary to popular opinion, most chaparral species are not adapted to frequent low-intensity fires. Bark measurements show that nearly all chaparral species have very thin bark making them very susceptible to cambium damage

and topkill by low-intensity fires burning on the surface (Dodge 1975). When the chaparral species invaded forests, grasslands, or woodland areas, they formerly were exposed to frequent low-intensity fires occurring at average intervals of 8 to 12 years or less. When the random distribution of fires with time produced low-intensity fires within intervals of 2 to 3 years in grass or forest litter, the chaparral species were almost totally eliminated. Under fire suppression policies of the past 70 years, most low-intensity fires of any appreciable size have been eliminated (California Division of Forestry 1972). As a result, the invading chaparral species have been permitted to survive and spread further.

In the natural chaparral habitat of shallow soils with low water-holding capacity, frequently upon steep slopes, the poor soils produce little or no herbaceous vegetation capable of sustaining frequent low-intensity fires. Chaparral normally grows in more or less even-age stands that become reestablished following high-intensity fires. Young chaparral plants, either seedlings or sprouts, are fire resistant and incapable of carrying fire.

The chaparral stands maintain their fire resistance until 15 or 20 years of age. By that time enough dead twigs and branches have accumulated to carry a fire through the brush during extreme fire weather conditions. By the time the chaparral stand is 30 to 50 years in age, it has accumulated a large enough quantity of dead fuels throughout the crowns of the plants to readily sustain the spread of high-intensity fires. Because of the fuel characteristics, fires in chaparral stands occur at intervals from 30 to 50 years. Where there is a litter accumulation, low-intensity fires can occur in stands of these ages under very moderate weather conditions such as early in the summer. But when they do occur, they normally are promptly suppressed. Almost all large fires in the chaparral are high-intensity fires at the present time because the low-intensity fires are put out.

In the last few years, work on the California Cooperative Soil-Vegetation Survey, financed by the California Division of Forestry, has developed further knowledge on the relations between vegetation and soil. Information on soil development processes substantiates the statements that many timber and grassland soils have been invaded and occupied by chaparral. Soil surveys in the central Sierra found extensive areas of timber soils now covered by dense stands of chaparral, confirming the observations by Wieslander (1935) that the timber had retreated ten miles or more in that area since the occupation of California by white man.

In San Diego County thousands of acres of Vista and Fallbrook soils, originally developed on a granitic parent material under a cover of oak woodland and grass, are now covered by dense stands of chaparral (Dodge 1975). The invasion was caused primarily by severe overgrazing. Removal of the grass acted in two ways. First, it reduced the competition for brush seedlings spreading from the small ecological niches they had previously occupied on Cieneba soils. Second, there was less fine fuel to carry frequent low-intensity fires that would have killed the fire-sensitive brush seedlings. Under the present fire protection policy, there are few low-intensity fires. Most fires are high-intensity fires that tend to perpetuate the chaparral species.

Better soils, invaded and occupied by dense stands of chaparral, tend to be degraded, losing both nutrients and water-holding capacity (Spurr 1964). While some erosion loss may occur from overgrazing or poor logging practices, the soil degradation that often follows high-intensity chaparral fires may be severe. The nutrients from the leaves, twigs and stems are left in a highly soluble form in the ash. They are readily removed by surface runoff and leaching. Surface soil particles on the bare, exposed soil are exposed to detachment and transport by raindrop impact. Puddling of bare soil surfaces frequently results from raindrop impact, increasing surface runoff and erosion (Calif. Div. of Forestry 1972).

In many cases high-intensity fires in chaparral also produce an impervious hydrophobic layer an inch or two beneath the soil surface. This impervious layer greatly facilitates erosional soil loss above the hydrophobic portion (DeBano, 1966; DeBano, Mann, and Hamilton 1970). Both soil and ground water storage are lowered because of the reduced infiltration.

Any easy, first step toward management of the present chaparral areas is to take advantage of the large fires to restore the ecological balance and stability. Use vegetation as a quick, simple method for surveying the soils. Where stands of natural or seeded grasses indicate grassland type soils use low-intensity prescribed burning in the grass to control the brush seedlings and sprouts.

Any sound management plan for California wildlands must consider soil types and capabilities. Fitting the vegetation to the soil can reduce nutrient losses and prevent further soil degradation now being experienced under chaparral cover. Restoring the natural vegetation can also reduce both direct fire losses

and the indirect damages caused by downstream flooding and sedimentation following high-intensity chaparral fires.

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REGROWTH RESPONSES OF CHAMISE FOLLOWING FIRE[1]

S. R. Radosevich, S. G. Conard and D. R. Adams[2]

Abstract: Shoot growth responses, plant water relationships, and photosynthetic ability of unburned chamise and shrubs regrowing following several controlled burns Nutritional, hormonal and environmental control of chamise shoot growth was also studied. The extrapolation of in vitro studies to the field situation suggest that water stress may physiologically mediate shoot growth by: direct reduction of carbohydrate or its availability to the shoot apex, a decrease in cytokinin at the apex, or an increase in inhibitor level in the shoot tip.

Key words: Adenostema fasciculatum; shoot growth; fire effects.

INTRODUCTION

Chamise (Adenostema fasciculatum H & A) is the most abundant shrub species of the California chaparral and many studies have been conducted concerning the seasonal growth cycle of this shrub. Chamise growth is usually initiated in January, increases through April and May and terminates in June (Bauer 1936, Cooper 1922, Hanes 1965, Jones and Laude 1960, Miller 1947). The plant also resprouts vigorously from a below ground burl following destruction of the shoots. Several factors have been suggested to control the growth cycle of chamise. Soil moisture, air temperature, soil temperature, insolation, relative humidity, and stored carbohydrates are some of the factors which have been reported to affect chamise shoot growth (Bauer 1936, Cooper 1922, Hanes 1965, Jones and Laude 1960, Miller 1947, Watkins and DeForest 1941). Few studies have been initiated on the growth responses of chamise following foliage removal.

The objectives of these studies were to determine the regrowth responses, plant water relationships, and photosynthetic ability of chamise shoots after top removal by controlled burning. A further objective was to determine if these responses varied according to the phenology of the shrubs at time-of-burn. Most environment-induced regulatory mechanisms of plant growth involve changes in endogenous balances of plant substances. An investigation of the relationship between nutritional, hormonal, and environmental influences on chamise shoot growth was also conducted.

Field Studies. An investigation was initiated in November, 1975 at Hopland Field Station, Mendocino County, California to determine the regrowth responses of chamise shoots following several controlled burns. The study site was a southwest facing slope at 900 m elevation. Five controlled burns (approximately 2.5 hectares each) were initiated from November, 1975 until September, 1976 (table 1). Fire temperatures at ground level and 2.5 cm below the surface were determined using TEMPILSTICKS™. Burn dates, fire temperatures, and shrub phenology for each controlled burn are presented in table 1. Shrubs were approximately 25 years old at the time of burning.

Shoot growth was determined by tagging 5 stems on each of 10 plants and periodically measuring their length. Shrub cover was also determined periodically at six different

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Burn Date	Temperature(F) Ground Level	Below Ground	Shrub Phenology
11/18/75	135-156	<100	Fall Quiescence
3/30/76	300-500	<100	Initiating Shoot growth
6/22/76	500-1300	<100-119	Full flower
8/2/76	500-1300	<100	Seed Development
9/15/76	1300-1600	<100-138	Summer Quiescence

Table 1. Burn dates, ground level and below ground fire temperatures, and general chamise phenology for five controlled burns.

locations ($3.4m^2$/location) within each burned area. The seasonal water potential of the regrowing chamise shrubs and an unburned stand of chamise was obtained by pre-dawn measurements with a Scholander pressure bomb (Scholander, Hammel, Bradstreet, and Hemingsen 1965). Three stems from three plants in each burned or unburned area were measured.

Photosynthesis of unburned and regrowing chamise shoots was measured using a constant flow $^{14}CO_2$ exposure apparatus (Shimshi 1969). In each plot three stems from three plants were exposed to $^{14}CO_2$ for a 10 second period. Photosynthetic measurements were made at light saturation levels (>1500 $\mu Em^{-2}sec^{-1}$). Exposed shoots were excised, stored at dry ice temperature, separated into leaves and stems, combusted, and $^{14}CO_2$ fixation was determined by liquid scintillation spectrometry. Dates for shoot growth, cover, water potential and photosynthesis measurements were: 2/21/76, 6/30/76, 8/31/76, 11/17/76, 1/5/77, 3/8/77, 4/28/77, 6/3/77, 6/21/77, 7/11/77; 6/21/77; 2/17/77, 4/29/77, 6/23/77; and 2/17/77, 4/27/77, 6/22/77, respectively.

Laboratory Studies. Chamise seedlings 25 to 50 cm in height were obtained from the Coast Range foothills near Dunnigan, California. Each seedling was transplanted in the field and later transferred to a controlled environmental chamber. Conditions were 16 hr. light (160 $\mu Em^{-2}sec^{-1}$ at leaf surface) at 29 C, and 8 hr. dark at 13 C. Plants were grown for at least 45 days before experiments were initiated.

The terminal 6 to 8 mm of shoots were excised, trimmed, surface sterilized and cultured on modified Murashige and Skoog (Murashige and Skoog, 1962) solid medium. Varying amounts of sucrose and growth regulators were added to the medium according to conditions prescribed for specific experiments. Each shoot tip was inserted upright on 2.5 ml of medium in a small test tube, sealed with a sterile plug and maintained under a 14 hr. photoperiod (25 $\mu Em^{-2}sec^{-1}$) at 20 C. After 7 days each shoot tip was examined for new leaf emergence.

Uniformly labelled sucrose[^{14}C] (specific activity 441.1 µCi/mmole) was used to determine ^{14}C accumulation at the shoot apex. Three µCi of radioactive sucrose were added to the basal medium in each test tube. After 1, 2, 3, 5 and 7 days, 4 shoot tips were removed from the culture tubes, and the apical portion was digested at 45 C for 48 hours in 1 ml of quatenary ammonium base solubilizer. ^{14}C-activity was determined by liquid scintillation spectrometry.

RESULTS AND DISCUSSION

Field Study. Chamise cover, xylem sap tension, and photosynthesis of regrowing shrubs following several controlled burns are presented in Table 2. Predawn water potential and photosynthesis were also determined for unburned chamise shrubs (table 2).

After each controlled burn, shoot growth was observed within 8 weeks after the fire occurred. This growth originated from the root-crown in a narrow band 0.5 to 2.5 cm below the soil surface. Because of differential burn dates, shrub cover decreased according to to the amount of time from the burn to the evaluation date (table 2). However, when shrubs were burned in the fall (11/18/75) or spring (3/30/76), rapid shoot growth was observed until midsummer when growth markedly slowed (figure 1). This cyclic pattern of growth was also observed for unburned chamise shoots, but growth rates of regrowing shoots greatly exceeded those of unburned shrubs (figure 1). Shrub cover (24 to 25.3%) and predawn xylem sap tension (9.7 to 25.3 bars) were greatest for shrubs resulting from these two burns (table 2). Of the five burned treatments, net photosynthesis was lowest (1.3 to 2.7 mg CO_2/gdw/hr) at these burn times.

The late summer burns (8/2/76 and 9/15/76) resulted in less cover by 6/21/77 (table 2) than other treatments. However, unlike in the earlier burns, growth did not cease during the winter months (figure 1). Predawn xylem sap tension was lowest for these treatments (4.8 to 8.5 bars) and photosynthesis was highest (table 1). The midsummer burn (6/22/76)

Burn Date	Cover (%)	Predawn Xylem Sap Tension (Bars)			Photosynthesis ($mg\ CO_2/gdw/hr$)		
	6/21/77	2/17/77	4/22/77	6/22/77	2/17/77	4/23/77	6/23/77
Unburned	-	9.3	10.5	20.3	0.8	0.9	1.7
11/18/75	24.0	9.7	11.9	25.3	1.7	1.3	2.1
3/30/76	25.3	9.7	10.0	14.7	2.2	2.0	2.8
6/22/76	17.0	8.7	5.9	12.1	1.1	2.8	3.4
8/2/76	14.2	8.5	4.8	7.3	1.5	2.9	3.9
9/15/76	10.4	-	5.3	6.2	0.7	3.4	3.9
$L.S.D._{.05}$		1.6	1.0	2.2	0.6	1.0	0.6

Table 2 -- Chamise cover, predawn xylem sap tension, and photosynthesis following several controlled burns.

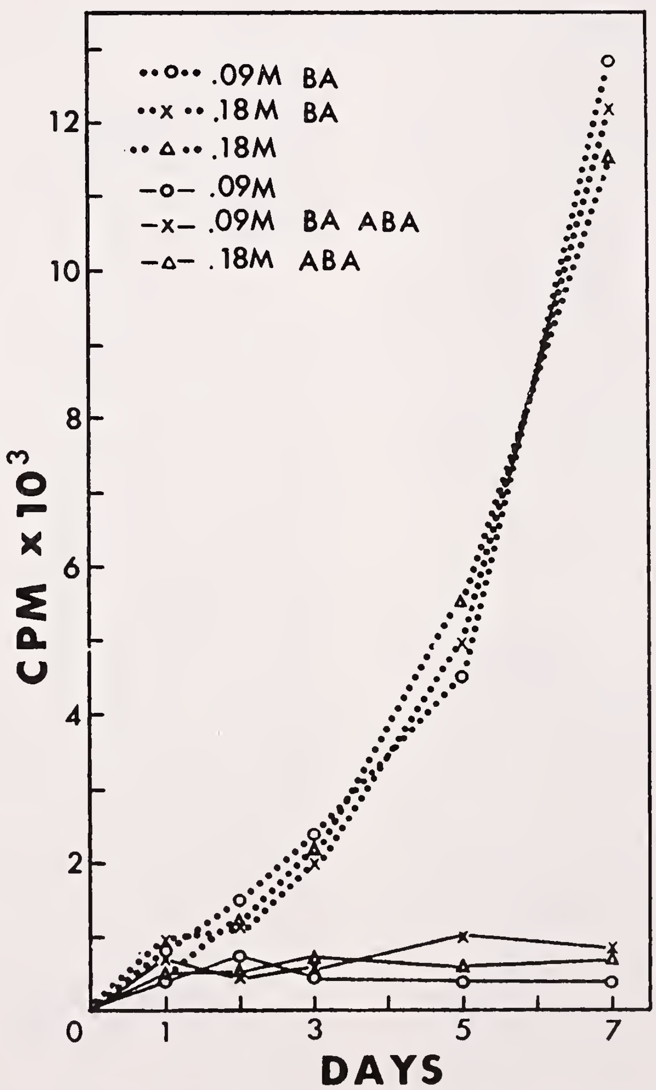

Figure 1 -- Shoot growth of unburned chamise shrubs and shrubs regrowing after five controlled burns. Arrows indicate dates of controlled burns.

resulted in cover, xylem sap tension, and photosynthetic values between those of the early and late burn dates (table 2).

Increasing xylem sap tensions were observed as the season progressed through spring and summer (table 2). The increased moisture stress did not result in photosynthesis decline; rather, photosynthesis increased through this time period (table 2). Predawn moisture stresses of 20.3 to 25.3 bars correlated with significantly lower photosynthetic rates (1.7 to 2.1 mg CO_2/gdw/hr) than xylem sap tensions of 6.2 to 7.3 bars (3.9 to 4.1 mg CO_2/gdw/hr). These data indicate that under moisture-limiting conditions, water stress is an important control on photosynthesis. However, where moisture is not at limiting levels, the dependence of photosynthesis on increasing temperatures is suggested.

Laboratory Studies. Preliminary experiments indicated that sucrose was necessary in order for chamise shoot tips to grow in culture. For example, only 10% of the shoot tips grew with 0.09 M sucrose, while 100% grew on 0.18 M sucrose. Shoots did not grow when sucrose was absent from the medium. Studies also revealed that when basal medium (0.09 M sucrose added) was supplemented with GA_3 (gibberelin A_3), IAA (indole-3-acetic acid), ABA (abscisic acid), or BA (benzyladenine), only BA significantly increased the percentage of shoot tips which grew. ABA, a noted growth inhibitor, was able to inhibit chamise shoot growth promoted by BA.

Benzyladenine Concentration (μM)	% Shoot Tips Growing — Sucrose (M) 0	0.09	0.18
0	0	5	80
10	0	85	90

Table 3 -- The interaction of sucrose and BA on the growth of cultured chamise shoot tips.
L.S.D.$_{.05}$ = 17%

Table 3 demonstrates an interaction of BA and sucrose for the growth of cultured chamise shoot tips. When sucrose was absent, no growth occurred, even if BA was present. At 0.09 M sucrose, BA increased the number of shoot tips growing from 5% to 85%. When sucrose was increased (0.18 M) in the medium, BA had no influence. If BA was not included in the culture medium, doubling the sucrose concentration caused dramatic increases in the percentage of shoot tips which grew. Thus,

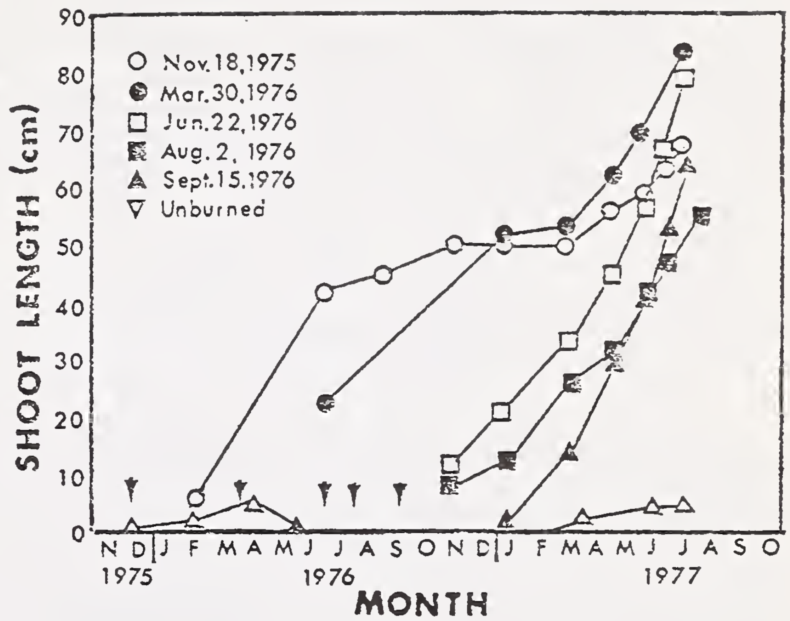

Figure 2 -- The accumulation of ^{14}C from sucrose[^{14}C] by chamise shoot tips at 1, 2, 3, 5, and 7 days after introduction into culture. L.S.D.$_{.05}$ = 602, 912, 1556, 1200 and 2021 CPM, respectively.

increasing sucrose levels resulted in a decreased BA optimum for the growth response (table 3).

The transport of sucrose[^{14}C] to the apical portion of the shoot tip was examined as a function of BA, ABA, and sucrose concentration in the culture medium (figure 2). After 2 to 7 days, the uptake of sucrose [^{14}C] separated into two groups: those which rapidly accumulated ^{14}C (0.18 M sucrose, 0.18 M sucrose + BA, and 0.09 M sucrose + BA), and those which did not (0.18 M sucrose + ABA, 0.09 M sucrose, and 0.09 M sucrose + BA + ABA) (figure 2). These data indicate a direct relationship between sucrose accumulation and the growth response observed in table 3. Treatments which did not promote sucrose[^{14}C] uptake were those which did not result in new leaf development, while those which promoted sucrose[^{14}C] uptake were those which promoted growth (table 3 and figure 2).

Cytokinins (BA) are known to influence the movement of nutrients in several plant systems. Amino acids, phosphorus and other

substances applied to leaves are known to move to the site of cytokinin application (Gunning and Barkley 1963, Kaminek 1965, Leopold and Kawase 1964, Mothes and Engelbrecht 1961, Müller and Leopold 1966, Quinlan and Weaver 1969, Shindy and Weaver 1967, Wickson and Thimann 1958). It is likely that cytokinins applied to chamise shoot tips via the basal medium create a mobilization center for sucrose at the apex. In the growth cycle of chamise the onset of shoot growth is correlated with a decrease in root starch concentration (Jones and Laude 1960). The ability of cytokinin to promote sucrose mobilization to the shoot tips in culture suggests that cytokinin is an endogenous agent governing the mobilization of carbohydrate (from reserves or photosynthesis) which accompanies the induction of shoot growth in chamise.

Data for chamise shoot growth (figure 1), xylem sap tension, and carbon fixation (table 2) have been presented. These data indicate an inverse relationship between xylem sap tension and shoot growth. An inverse relationship between xylem sap tension and production is also indicated (table 2). The extrapolation of *in vitro* studies to a field situation suggests that regulation of chamise shoot growth by water stress may be physiologically mediated by a direct reduction of carbohydrate or its availability to the shoot apex, a decrease in cytokinin at the apex, or an increase in inhibitor level in the shoot tips.

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FIRE HISTORY, ENVIRONMENTAL PATTERNS, AND SPECIES PATTERNS IN SANTA MONICA MOUNTAIN CHAPARRAL[1]

Jonathan D. Sauer[2]

Abstract: Natural vegetation of the Santa Monica Mountains evidently was adapted to a regime of infrequent, large, intense, non-selective fires, which has not been substantially altered by man. Data from a few transects in recent burns suggest an hypothesis that species distributions are controlled by physical environmental variables and persist, over the long run, unchanged by repeated fire episodes. With the possible exception of some ephemerals, changes in species composition in burns do not fit classical succession models involving micromigrations and autogenic habitat modification.

Key words: fire ecology, Southern California vegetation.

FIRE HISTORY

The rugged and still largely undeveloped Santa Monica Mountains lie along the coast of western Los Angeles County and eastern Ventura County. Their natural fire regime was intermediate between those of the interior Transverse Ranges and the Channel Island offshore. Presumably, the Transverse Ranges had a relatively fine-grained mosaic of uneven aged vegetation due to frequent summer lightning fires, the Channel Islands had uniformly ancient vegetation with no fire history, and the Santa Monicas had extensive areas of even-aged vegetation that post-dated great fires. These fires must have been infrequent, awaiting accumulation of a continuous fuel track in old vegetation and unusually persistent Santa Ana winds to carry fires ignited in the interior to the coast. The remarkable absence of native conifers in the Santa Monicas may be due to the rarity and consequent intensity of fire.

There is no historical evidence of vegetation burning by the Chumash or other local Indians nor has the natural fire regime been substantially altered by modern human intervention. Many fires are now ignited by man but they are usually suppressed, especially if burning in mild weather. Since there is almost no decomposition of dead vegetable matter in Southern California, fuel accumulates until an old-time holocaust is inevitable. Since 1970 there have been three major fires in the Santa Monicas. In the fall of 1970 the Malibu fire burned 27,000 acres; there were two fires in the fall of 1973, the Mugu fire burning 14,000 acres and the Topanga-Tuna Canyon fire burning 2,500 acres. All three fires were generally clean burns skipping only some canyon woodland. All three were carried by strong Santa Ana winds until reaching the coast or until a sea breeze set in.

PATTERNS IN THE THREE BURNS

These recent burns extend from sea level to over 800 meters elevation and include great diversity of geology, topography, and microclimate. It has gradually dawned on me and several biogeography students in my department

[1] Presented at the Symposium on Environmental Consequences of Fire and Fuel Management in Mediterranean Ecosystems, Palo Alto, Calif. Aug. 1-5, 1977.

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that intensive study of these areas through time would be worthwhile but we are just now beginning to work out a systematic approach. This differs from the usual ecosystems approach in which areas are sampled as examples of types within which data are pooled. Instead we are taking a geographic point of view and focusing on concrete spatial distribution patterns of plants and environmental variables.

Transects are being run along contours as continuous belts 50 meters in length. Presence of species is recorded above each square meter. Data from a few of the most recent transects are offered here as a basis for tentative working hypotheses. The transects are in sequence of increasing elevation of the site. Species occurences are expressed as frequencies per 100 meters.

Scrub Vegetation

Since the Wieslander vegetation type maps of the 1930's, Santa Monica Mountain scrub has traditionally been classified into three types: sagebrush=coastal sage=soft chaparral, chamise chaparral, and tall mixed chaparral. These types, in that order, have been correlated with increasing moisture, which is partly a function of increasing elevation. Also it is generally accepted that on moist enough sites the three, in the same order, form a successional series, the soft chaparral pioneering after disturbances, including fire. This is no doubt true on a highly generalized level but concrete meso-scale and micro-scale patterns within the scrub are far too complex to be so easily characterized.

The sample transects presented here are selected from a very limited range of Santa Monica Mountain environments: they are all taken from recently burned sites on the coastal side of the mountains; they are all on thin, azonal soils on steep slopes on Tertiary sedimentary rocks. The transects were placed without considering plant species present yet they all show unique species mixes, none of which are exactly typical of the traditional types.

Big Sycamore Canyon

The following frequencies are from a transect run 3 years and 8 months after the Mugu fire, elevation 70 meters, sandstone substrate, slope 20° to 30° facing SW to SE, with nearly complete cover of brush 1 to 2 meters tall.

Herbs--Stipa lepida 32, *Bromus rubens 12, Thelypodium lasiophyllum 8, *Euphorbia maculata 4, Stephanomeria virgata 2.

*Asterisks indicate exotics.

Seedling Shrubs--Lotus scoparius 100, Salvia mellifera 36, Eriogonum fasciculatum 14, Artemisia californica 12, Solanum xantii 4, Mimulus longiflorus 4.

Resprouting Shrubs--Adenostoma fasciculatum 46, Rhus laurina 26, Ceanothus spinosus 10, Yucca whipplei 8, Sambucus mexicana 4, Rhamnus crocea 2.

Convolvulus cyclostegia vines blanketed this site for the first two years after the fire but have now disappeared. The site is about a mile from the sea and at the lower limits of chamise chaparral in this canyon. Nearby slopes are dominated by seedling soft chaparral species with a scattering of trees that are sprouting from the roots, mainly Heteromeles arbutifolia and Juglans californica. Tree tobacco (*Nicotiana glauca) is participating in revegetation of burns nearby.

Tuna Canyon

The following frequencies are from two adjacent transects run 3 years and 7 months after the Topanga-Tuna fire, elevation 80 m, on sandstone, the first on a 10° to 20° slope facing NNE to NNW, with dense brush 1 to 2 m tall.

Herbs--Convolvulus cyclostegia 66, Elymus condensatus 60, *Lolium perenne 32, Viola pedunculata 20, *Anagallis arvensis 12, *Sonchus oleraceus 8, *Erigeron sp. 8, Emmenanthe penduliflora 2, Phacelia sp. 2, Gnaphalium bicolor 2.

Seedling Shrubs--Salvia mellifera 26, Eriogonum cinereum 18, Haplopappus squarrosus 16, Artemisia californica 12, Lotus scoparius 12, Solanum xantii 6, Malacothrix saxatilis 6, Diplacus longiflorus 4, Rhus laurina 4, R. ovata 2.

Resprouting Shrubs--Rhus laurina 52, Heteromeles arbutifolia 4.

The second Tuna Camyon transect is from a 20° to 45° slope facing SSW to W, with dense brush 1 to 3 m tall.

Herbs--*Lolium perenne 62, Convolvulus cyclostegia 36, Phacelia hispida 16, Elymus condensatus 14, Emmenanthe penduliflora 8, Gnaphalium bicolor 4, Stachys quercetorum 4, Venegasia carpesioides 2, *Bromus rubens 2.

Seedling Shrubs--Lupinus scoparius 62, Solanum xantii 36, Malacothrix saxatilis 30, Salvia mellifera 16, Lotus scoparius 10, Eriogonum cinereum 8.

Resprouting Shrubs--Rhus laurina 16, R. integrifolia 2.

This site is about the same elevation and distance from the sea as the Big Sycamore site but the steeper slope may make it too dry for hard chaparral. No living plant tissue survived the burn above ground although there are many dead snags, mostly of Rhus laurina, 3 to 4 m tall. The area was blanketed by a diverse mixture of native wildflowers and masses of Convolvulus cyclostegia for two years after the burn. The grasses, both the perennial native Elymus and the annual Italian Lolium, are also already declining in importance.

Topanga Canyon

The following frequencies are from a transect run 3 years and 7 months after the Topanga-Tuna fire, elevation 270 m, sandstone and conglomerate substrate, slope 10° to 30° facing SSW, with dense brush 2 to 3 m tall.

Herbs--Convolvulus cyclostegia 18, Phacelia hispida 16, Eucrypta chrysanthemifolia 8, *Brassica sp. 6, Cuscuta sp. 4, Phacelia grandiflora 2.

Seedling Shrubs--Malacothamnus fasciculatus 38, Solanum xantii 12, Eriogonum fasciculatum 8, Malacothrix saxatilis 6, Ceanothus megacarpus 2.

Resprouting Shrubs--Ceanothus spinosus 32, Rhus laurina 32, Rhamnus crocea 6, Ribes malvaceum 4.

Only a few dead snags, 3 to 4 m tall of the two Ceanothus species and Rhus laurina, were left above ground after the fire. Marah macrocarpa and other ephemerals that dominated the site for the first two years are now declining or gone. Dendromecon rigida was an abundant post-fire dominant on some nearby sites but declined rapidly in vigor, especially where Ceanothus megacarpus seedlings are taking over.

Los Leones Canyon

The following frequencies are from two adjacent transects run 3 years and 8 months after the Tuna-Topanga fire, elevation 280 m, conglomerate substrate, the first on a 20° to 25° slope facing W, with very dense brush 2 to 3 m tall.

Herbs--*Brassica geniculata 84, Convolvulus cyclostegia 24, Elymus condensatus 2.

Seedling Shrubs--Ceanothus megacarpus 58. Solanum xantii 28, Lotus scoparius 12, Salvia mellifera 10, Eriogonum cinereum 2, Rhus laurina 2, Yucca whipplei 2.

Resprouting Shrubs--Ribes malvaceum 14, Rhus laurina 14, Salvia mellifera 6, Rhamnus crocea 2.

The second Los Leones transect is from a 30° to 35° slope facing NW.

Herbs--*Brassica geniculata 90, Phacelia sp. 14, Elymus condensatus 4, Venegasia carpesioides 2.

Seedling Shrubs--Ceanothus megacarpus 38, Solanum xantii 8, Lotus scoparius 8, Eriogonum cinereum 6, E. fasciculatum 2, Rhus laurina 2, Salvia mellifera 2, Malacothrix saxatilis 2.

Resprouting Shrubs--Ribes malvaceum 20, Ceanothus spinosus 16, Rhus laurina 8, R. ovata 8, Rhamnus crocea 4.

There were some cool spots in draws in which Salvia mellifera bushes were scorched but resprouted. Most of the site had little but scattered dead snags, up to 4 m tall, of the two Ceanothus species and Rhus laurina. The early post-fire herb blanket is now disappearing except for the annual Brassica.

Saddle Peak

The following frequencies are from a transect run 6 years and 9 months after the Malibu fire, elevation 700 m, sandstone substrate, 20° to 25° slope facing NNW, with fairly dense brush 1 to 3 m tall.

Herbs--*Bromus spp. 38, Chlorogalum pomeridianum 22, *Brassica geniculata 12, Penstemon centranthifolius 4, Delphinium cardinale 2.

Seedling Shrubs--Ceanothus megacarpus 76, Arctostaphylos glauca 22, Adenostoma fasciculatum 8, Salvia mellifera 2.

Resprouting Shrubs--Adenostoma fasciculatum 36, Quercus dumosa 16, Heteromeles arbutifolia 6, Rhamnus californica 2.

The burn left little above ground except snags of *Heteromeles* and *Quercus dumosa*, mostly 3 to 5 m tall. The area became overstocked with *Arctostaphylos* and *Ceanothus* seedlings, some of which are dying, along with the early post-fire pioneers. Nearby sites in the same burn dominated by a mixture of *Adenostoma sparsifolium* and *A. fasciculatum* had masses of *Dendromecon rigida* as early pioneers.

Borders with Woodlands

In some of the deeper rocky canyons within the general fire perimeters, sharply defined woodland patches escaped burning, including groves of *Acer macrophyllum*, *Umbellularia californica*, and *Alnus rhombifolia*. More generally, gallery woodlands of *Quercus agrifolia* and *Platanus racemosa* were severely scorched; most of the trees survived and crown sprouted but in the two larger burns significant proportions of the oak trees, including some large ones, were killed. Mortality of these was sufficient to open up some gallery woodlands into park savannas. In the aboriginal system without grazing by livestock, such mortality may have been offset by reproduction of oaks between burns. Presently there are few young oaks.

Borders with Park Savannas and Open Grasslands

The fires crossed various borders between scrub and park savannas and grasslands, evidently with little lasting effect on location of the border. The park savannas and grasslands have the characteristic California complex of native woody plants, mostly *Quercus agrifolia* and *Q. lobata* here, with a ground layer of exotic herbs. The first two years after the fires saw spectacular outbreaks of native annual and perennial wildflowers that have since been overwhelmed by resurgence of the annual grasses and other exotic herbs. After observing this in the Mugu burn, state park officials are planning controlled burns of some grasslands to encourage native flowers and bunch grasses. I am skeptical whether increased frequency of fire will accomplish this but hope to monitor the experiments with permanent transects.

HYPOTHESES

This extremely sketchy background suggests some tentative working hypotheses. Distributions of Santa Monica chaparral species may be controlled in the long run by physical environmental variables such as geologic substrate, topography, and climatic gradients. Fire, unlike these controls, is not an independent variable. Obviously, fires have great temporary effects on species abundance but the effects are cyclical rather than lasting. If the borders of plant species are defined to include viable seed stores below ground and living, resprouting rootstocks, the Santa Monica patterns may be considered essentially in equilibrium. Some of the early post-fire pioneers may have dynamic micromigrations but most of the post-fire vegetational changes are not truly successions in the sense of colonizations dependent on autogenic habitat modification. They are more comparable to year to year changes in desert vegetation with variations in rainfall. Of course, the chaparral species geography would be different in another fire-free system, just as they would be different if the climate changed, but within the actual existing system, fire cannot be invoked as a primary control of spatial distributions.

THE RELATIONSHIP OF PRECIPITATION TO POST-FIRE SUCCESSION IN THE SOUTHERN CALIFORNIA CHAPARRAL[1/]

Sterling C. Keeley[2/]

Abstract: Succession of herbaceous and shrubby species was studied over a four year period in San Diego County. Sampling was by the line intercept method. Herb cover fluctuated between years of high cover and year of low cover, alternately. Subshrub cover increased through the third year post-fire and decreased the fourth year. Shrub cover increased gradually through all years. The fluctuations in herb cover were associated with rainfall. A pictorial model is presented showing the relationship between herb cover and precipitation.

Key words: California, chaparral, fire, herbs, succession

INTRODUCTION

Fire is an integral part of the California chaparral. Each year large areas of this dense brush vegetation burn in southern California. A successional sequence is initiated after fire in which herb species not commonly found in the mature vegetation, appear in abundance. These species have been called "fire annuals" indicating their close association with fire. Shrub species also reappear soon after fire, resprouting from below ground burls or roots, or germinating from seeds scarified by the fire.

Specifics on shrub succession are similar in most studies and there is general agreement on the response of brush species to burning (Sampson 1944, Horton and Kraebel 1955, Hanes and Jones 1967, Hanes 1971). Herb succession has been given less attention however, and details of post-fire herb growth are unclear. Several studies on post-fire succession have included herbs (Sampson 1944, Horton and Kraebel 1955, Sweeney 1956, Vogl and Schorr 1972, Christensen and Muller 1975), but few generalizations have emerged from these works due to differences in location, methods and focus. Most studies show abundant herb growth the first year after fire followed by a general decrease in herbs and replacement by shrubs in later years. There are several reports however, of high herb growth again after the first year, and before the fifth post-fire year (Sampson 1944, Horton and Kraebel 1955, Sweeney 1956), but there is little apparent similarity between studies in the timing of this second peak of herb growth. Although much is known of recovery after burning in the chaparral, it is apparent that the factors which control herb growth and the sequence of events in herbaceous succession are in need of further study.

An excellent opportunity to study post-fire succession in both herbs and shrubs was provided by the Laguna Fire of 1970 in San Diego County. During late September and early October over 70,000 hectares of chaparral were burned. This large even-aged burned area allowed study and comparision of sites at several (three) elevations and over the four major slope faces at each elevation. Sites were chosen at 560 m, 1000 m and 1670 m in a transect running approximately parallel to Hwy 8 . The composition of herbs, the change in numbers of species, cover and the general importance of herbs, subshrubs and shrubs were observed at these sites for four years after the Laguna fire (1971-1974).

RESULTS

The changes in herb cover during succession are shown in fig. 1, for the mid-elevation site

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1/ Presented at the Symposium on Environmental Consequences of ire and Fuel Management in Mediterranean Ecosystems, Palo Alto, Calif. Aug. 1-5, 1977.

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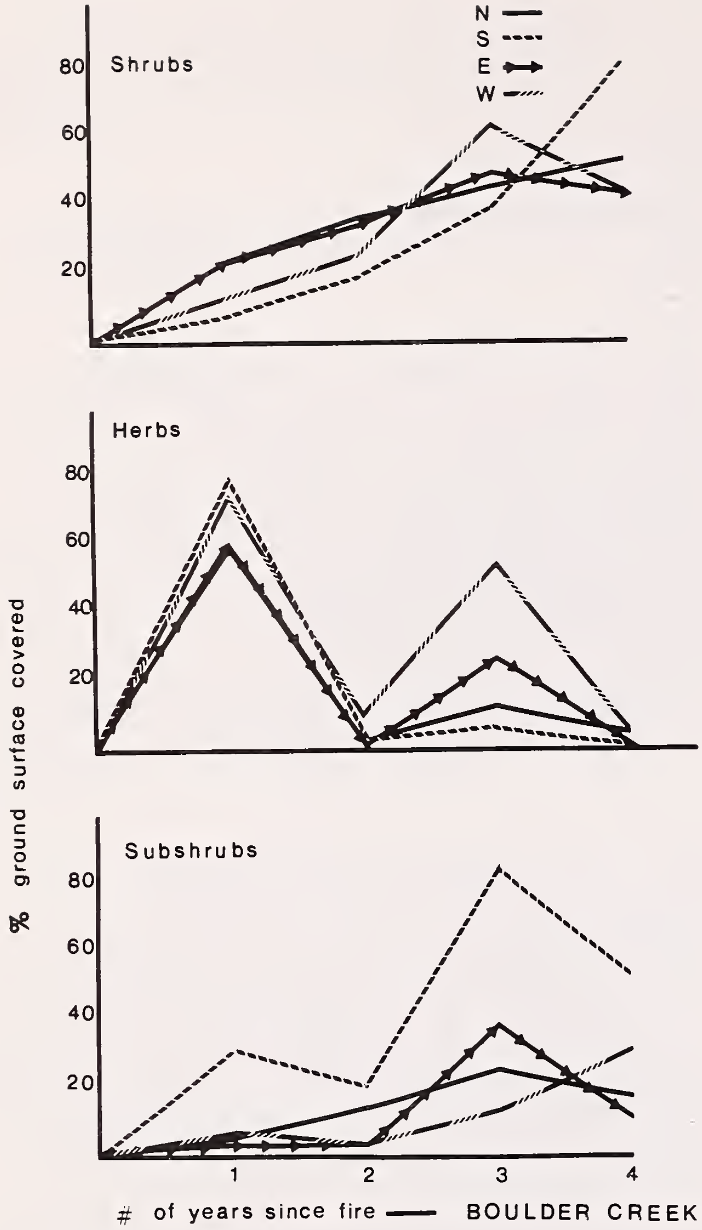

Figure 1--Percent cover by slope of shrubs, herbs and subshrubs at the mid-elevation site, Boulder Creek.

at Boulder Creek. The patterns seen in this figure are representative of those at all sites. Herb cover was highest the first year after fire and next highest the third post-fire year. Cover was extremely low both the second and fourth years after fire. Maximum cover was obtained on the south facing slope at all sites, the first year after fire, but was least on this slope in later years. Cover ranged from 40-80% ground surface covered the first year and from 20-40% cover the third year after fire. Cover values were slightly lower at the low elevation site than at the mid- or high elevation study areas.

Diversity (number of species) also went from high to low in alternate years, following cover. More species were found the first year after fire in all sites but one, and decreased over time generally, without regard to slope or elevation. The least number of species was found on the south facing slope the first post-fire year; the maximum number of species was found on the other slopes, but varied with the site. The third year post-fire diversity and cover were high on the same slope face at all sites.

Subshrubs increased through the third post-fire year when they reached a peak in cover (fig. 1) as well as diversity. Cover of subshrubs was generally highest on the south facing slope in all sites. The two most abundant species of subshrubs were Lotus scoparius and Helianthemum scoparium. Subshrubs were not present in appreciable numbers at the high elevation site.

Shrub cover increased throughtout the study period, reaching high levels the fourth year after fire. Cover was highest on the south facing slope at the mid-elevation site as shown (fig. 1), but was comparable between slopes at the high and low elevation sites. Diversity of shrubs was greater on the north and east facing slopes; the south facing slope had a high proportion of Adenostoma fasciculatum at all sites. Non-sprouting species also occurred in all sites, however.

DISCUSSION

The patterns of succession in herbs are similar to those observed in other studies with the first year high and another year of relatively high herb growth later in succession (Sampson 1944, Horton and Kraebel 1955, Sweeney 1956). In other studies the peak of herb growth after the first year appeared sometime before the fifth year post-fire, but the cause of this renewed growth was rarely discussed. Sweeney (1956) found that germination requirements of herbs which appeared after fire varied and that the time at which some species appeared was due to individual requirements for suitable growing conditions. In several species these conditions were met immediately after fire, such as Phacelia brachyloba and in others were not achieved until later in succession. McPherson and Muller (1969) found that removal of allelopathic agents by denaturation and leaching allowed herb growth where none had previously been possible, and Sampson (1944) and others noted the improved conditions of light, nutrients and moisture for herb growth after fire in the chaparral. These features are without doubt important in herb succession, but given the similarity in overall patterns of herb cover, that is high and low years of herb growth during succession, but at different times in each study, it seems reasonable to

suspect that some other factor may also play an important role.

Of the many possible factors which could affect herb growth during post-fire succession few seem as obvious or as rarely discussed as precipitation. Rainfall strongly influences growth and survival of shrub species in the chaparral (Mooney and Chu 1972, Dunn 1975), and is important in development and production of seeds (Keeley 1977). While the phenological patterns of herbs are different than that of shrubs dependence on moisture for growth is quite similar. All growth and seed production must take place before the onset of summer drought (Slade, Horton & Mooney 1975). It is the relationship between rainfall and herb growth that will be discussed here. A full discussion of the results is given elsewhere (Keeley submitted).

Rainfall data for the three study sites is given in figure 2. Moderate to high precipitation was recorded at all sites in 1971, the first year after fire and in 1973 the third post-fire year. Low levels of rainfall were recorded in 1972 and 1974. Herb cover was high in 1971 and 1973 and low in the intervening years, paralleling the pattern of rainfall.

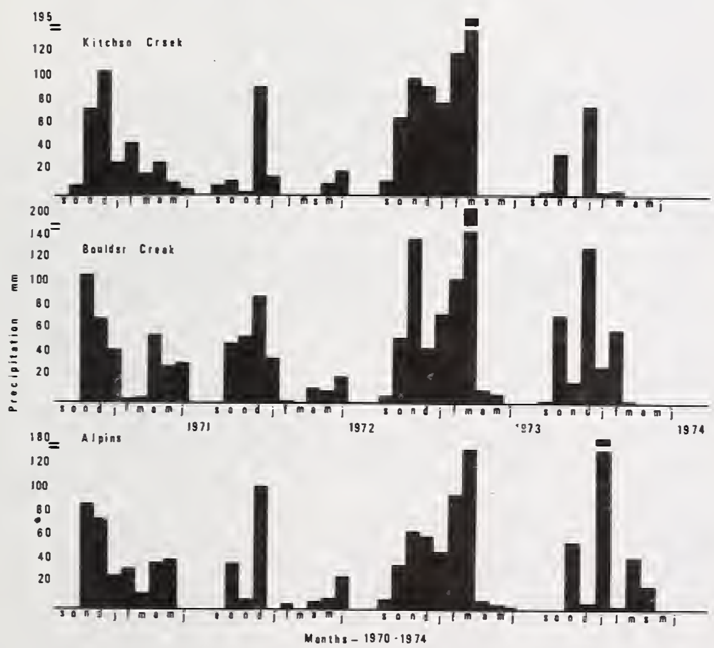

Figure 2--Precipitation from September to June 1971 to 1974 for the three study sites.

The relationship between increased rainfall and high herb growth has been noted briefly in other studies (Sampson 1944, Sweeney 1956), but little importance has been attached to the possible role of precipitation in succession. Sampson (1944) reported high herb cover the first year after fire, as is typical of most studies (e.g., Horton and Kraebel 1955, Sweeney 1956, Vogl and Schorr 1972, Christensen and Muller 1975), but also reported high cover in two and three year old burned areas. In each case when herb cover was high after the intial first year bloom it occurred in years of high precipitation. Went, Juhren and Juhren (1952) also found that precipitation affected herb growth; they concurred with Sampson (1944) in saying that either a very dry or very wet season could produce an unpredictable effect on the plant populations in burned areas. Horton and Kraebel (1955) found that high levels of rainfall caused increased herb growth and conversely, when rainfall was below normal herb growth was also below normal. On the basis of these studies and on evidence obtained in this investigation it is apparent that precipitation is important in determining herb cover after fire. A pictorial model of this relationship is shown in figure 3.

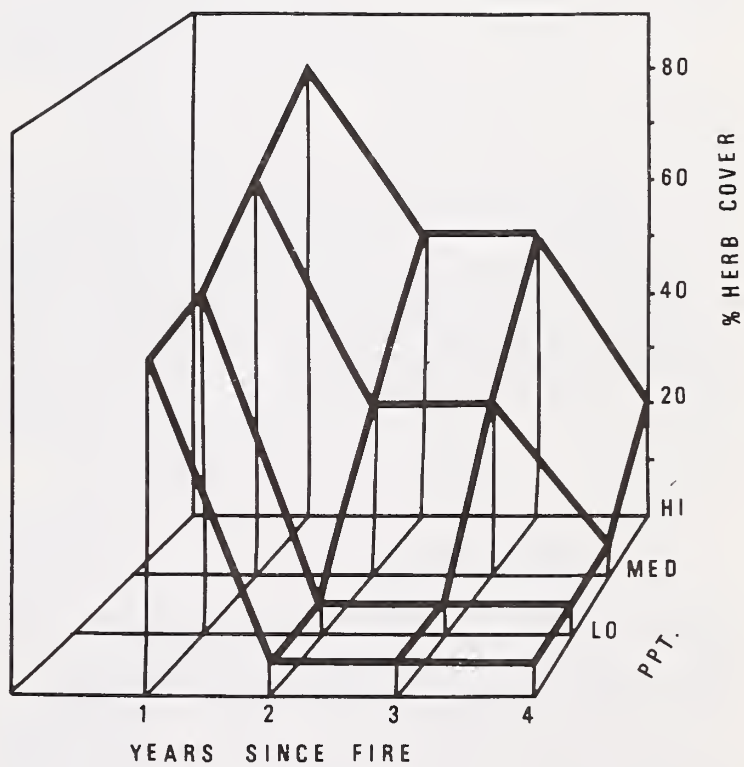

Figure 3--Model of post-fire herb cover as influenced by precipitation.

In this model herb cover is highest the first year post-fire, although maximum values for cover will only be reached if rainfall is adequet. Christensen and Muller (1975) found that herb growth was high the first year regardless of drought conditions and this is represented in the model. However, Horton and Kraebel (1955) found that severe

drought reduced herb growth even the first post-fire year. Herb cover will be high the second through the fourth years after fire if rainfall is moderately high to normal, but will be low if drought conditions prevail.

In the model (fig. 3) maximum herb cover is obtained the first year after fire and is not as high again despite adequet rainfall. This reflects the drop in cover seen at the study sites used here and in the literature (Sampson 1944, Horton and Kraebel 1955, Sweeney 1956). By the fourth year after fire herb cover declines so that even with relatively high amounts of rainfall herb cover will be lower than in other years. Beyond the fourth year shrub cover is high and herb cover very low. Using this conceptual model it is relatively simple to explain the varying reports in the literature (see above) of peaks in herb abundance the second or third year after fire, at different sites, elevations and slopes, and the wide differences in total herb cover from one study to the next (see Horton and Kraebel 1955 vs. Sampson 1944). These fluctuations in cover can be understood in terms of available moisture, or rainfall.

This model is concerned with predicting herb cover and variations in cover during succession. The species of herbs which will appear in any given year are not accounted for by this model and will appear due to their individual tolerances and requirements for germination. Species groups have been identified during succession (Keeley submitted) but again are not dependent on rainfall. Precipitation will determine however the amount of species which are suited to each year after fire and may influence the composition of the soil seed population, thus influencing the next successional sequence.

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FIRE-DEPENDENT REPRODUCTIVE STRATEGIES IN ARCTOSTAPHYLOS AND CEANOTHUS[1/]

Jon E. Keeley[2/]

Abstract: The question is addressed "why have the majority of Arctostaphylos and Ceanothus species apparently (through evolutionary time) lost the ability to resprout after fire." It is proposed that loss of the sprout-producing burl was adaptive in an environment which put a premium on seedling establishment over sprouting. The hypothesis is offered that this environment was one in which there were (occasionally) long fire-free periods. This was tested by comparing regional and elevational patterns of lightning fires with patterns of abundance and diversity of nonsprouting and sprouting Arctostaphylos and Ceanothus.

Key words: Arctostaphylos; Ceanothus; lightning; fire; reproductive strategies.

INTRODUCTION

Wildfires are frequent in the California chaparral. The reasons are 1) man provides a ready source of ignition, 2) the Mediterranean-climate summer drought produces a very flammable vegetation, and 3) the dense nature of the vegetation results in a very rapid and extensive fire spread. Even though man has been a part of this ecosystem for a relatively brief 15,000 yrs (Martin 1973) it is almost unquestionable that fire has been an important selective force in this system for a much longer time. This is based on a number of observations. One is that the mediterranean climate, and consequently the flammability characteristics of the vegetation date back to at least the Pliocene epoch 10 million yrs ago (Axelrod 1973). A second is that lightning presently is a natural source of fire and there is little reason to suspect it hasn't also been in the past. Thirdly, chaparral shrubs have several specialized structural adaptations which provide for their rapid reestablishment after fire. For example, seeds which remain dormant in the soil until stimulated by fire and basal burls which send up a proliferation of new shoots. These observations make it reasonable to assume that fire has been a major evolutionary force in this vegetation.

From a fire-management point of view an understanding of the dynamics of shrub reestablishment after fire is vitally important and this is dependent upon an understanding of the reproductive strategies evolved by these shrubs.

As mentioned, shrubs reestablish after fire by seedlings and/or resprouts from belowground vegetative parts (not all resprouting species posses burls). The dependence upon seedlings or resprouts varies from species to species as well as from population to population within a species. Schematically we can picture a species' reproductive tactic falling somewhere along the abscissa of the graph in figure 1. However, this position will vary spatially (from population to population) and temporally (from one fire to the next). A species is then best characterized as having a reproductive strategy which occupies a region along the abscissa (see Keeley and Zedler 1977). Thus, since Quercus sp. for example resprout but establish very few seedlings after fire they would occupy the region (a) farthest to the left. Proceeding to the right we pick up Prunus sp.,

1/ Presented at the Symposium on Environmental Consequences of Fire and Fuel Management in Mediterranean Ecosystems, Palo Alto, Calif. Aug. 1-5, 1977.

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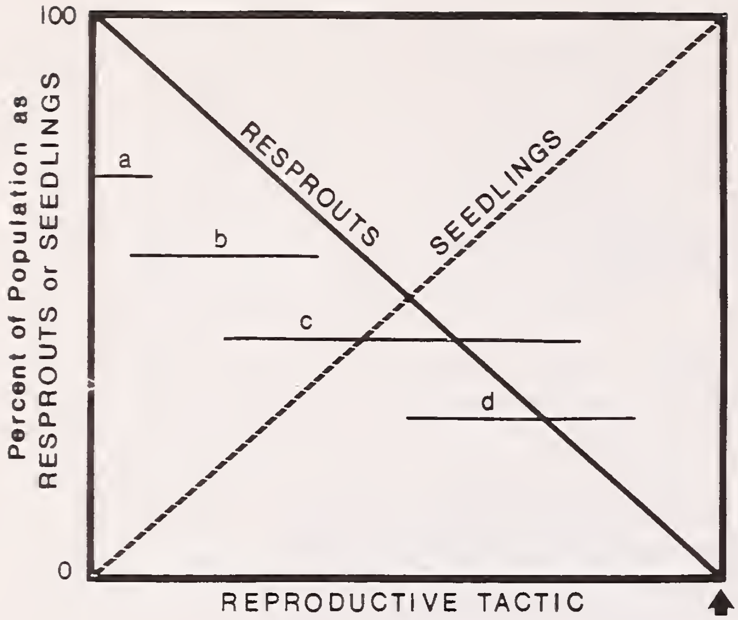

Figure 1--Reproductive options available to chaparral shrubs.

Rhamnus sp., Heteromeles arbutifolia, Rhus ovata, certain Arctostaphylos sp. and Cercocarpus sp. (region b), and the nearly ubiquitous Adenostoma fasciculatum would likely occupy the broadest region perhaps around the middle of the axes (c) followed by certain Ceanothus sp. to the right of center (d). There is however one group of species which form a significant exception to this pattern. The majority of Arctostaphylos and Ceanothus species do not occupy a region along the abscissa but rather a single point. These species are totally incapable of resprouting under any condition and thus are entirely dependent upon seedling production for post-fire regeneration. They are obligate-seeders.

We can therefore define two groups of species; those that resprout after fire and those that don't. Resprouters occupy a region along the reproductive tactic axes, the position being determined by the individual species' resistance to fire and the intensity of the fire both of which will be affected by a multitude of factors such as age of the shrubs, density of the vegetation, season of the fire, weather patterns prior to, during, and after the fire, being very important. Nonsprouters can operationally be defined as incapable of resprouting under any condition in which the tops are removed, by fire or any other means. It is this group of shrubs composed entirely of Arctostaphylos and Ceanothus species which I will focus on in this paper.

The very different response to fire of sprouters and obligate-seeders raises some questions. It would seem that a long-lived species with the ability to survive fires and resprout vigorously should have a tremendous competitive advantage. Once such a species had appropriated space it would occupy it for a long time. After fire, the well-developed root system should allow for a greater allocation of resources to aboveground growth thus making it almost immune from serious competition for some yrs. In addition these resprouts are capable of heavy seed production within the second yr after fire whereas seedlings may require upwards of 10 yrs before a significant seed crop is produced.[3]

In contrast, the obligate seeding life-history seems less obviously advantageous. Since all of the shrubs die in the fire and no significant seed germination takes place except after fires, species with this life-history are dependent upon accumulating seeds in the soil. This would suggest allocation of a large proportion of energy to annual seed production. But some balance must be struck between growth and reproduction. Too much allocation to growth would be risky should the interval between fires occassionally be relatively short. It seems that a species that loses completely the ability to resprout would be in a far more precarious position than one which could sprout to at least some extent.

Evidence based mainly on systematic considerations is quite convincing that the obligate seeding species of Arctostaphylos and Ceanothus were derived from sprouting ancestors, i.e., evolutionarily they have lost the ability to resprout (Wells 1969, Stebbins 1974, p. 192). This, coupled with the fact that the majority of species in these two genera (the largest shrubby genera in the chaparral) are obligate-seeders and they form a very significant part of the chaparral community suggests there must be an adaptive advantage to reestablishing entirely by seedlings.

HYPOTHESES

Two hypothetical advantages to be gained by not producing a burl are:

1) a genetic advantage
2) an ecological advantage

A genetic advantage could arise as follows. Under conditions of recurring fire the loss of the burl would mean a greater number of sexual generations resulting in a greater frequency of natural selection (Wells 1969). This implies that obligate-seeding species are capable of a closer and more rapid adjustment to the environment than resprouting species (Raven 1973). Thus by establishing each new generation with

[3] Personal observations.

sexually produced progeny nonsprouting species gain some sort of evolutionary advantage over already established individuals.

This hypothesis is not overly compelling. One reason is that nonsprouters do not appear to have any such obvious advantage; sprouting species are very successful. That is, sprouters and seeders coexist so we simply can't explain the advantage of one group at the expense of the other. A second reason is that the sprouting species of *Arctostaphylos* and *Ceanothus* also produce many seedlings. The genetic hypothesis argues that these sprouting forms could gain an advantage by not sprouting in that there would be greater space and resources for their seedlings and consequently more seedlings would establish and consequently there would be greater genetic variation for natural selection to act on. However, this advantage must necessarily be shared with seedlings of all other species. It is certainly questionable whether or not the small increase in seedling number and the consequently slight increase in genetic variability are sufficient to cause complete loss of the burl.

The ecological hypothesis argues that the obligate-seeders evolved in an environment which favored the establishment of seedlings and concomitantly put less of a premium on resprouting. A corollary to this may be that the complete loss of the burl was of selective value because of the energetic gain to accrue by no longer allocating energy to burl production or maintainance.

What sort of environment was it? First, seedlings do not establish in mature chaparral; they are adapted to openings. Secondly, openings generally occur only after fires. Thirdly, in the postfire environment seedlings stand very little chance in close competition with resprouts. Therefore, situations which result in the fewest resprouts after a fire will produce the optimum environment for seedlings.

Based on these observations one could hypothesize a number of such situations. While acknowledging that there is no compelling evidence for accepting any one answer I would like to propose one such hypothesis.

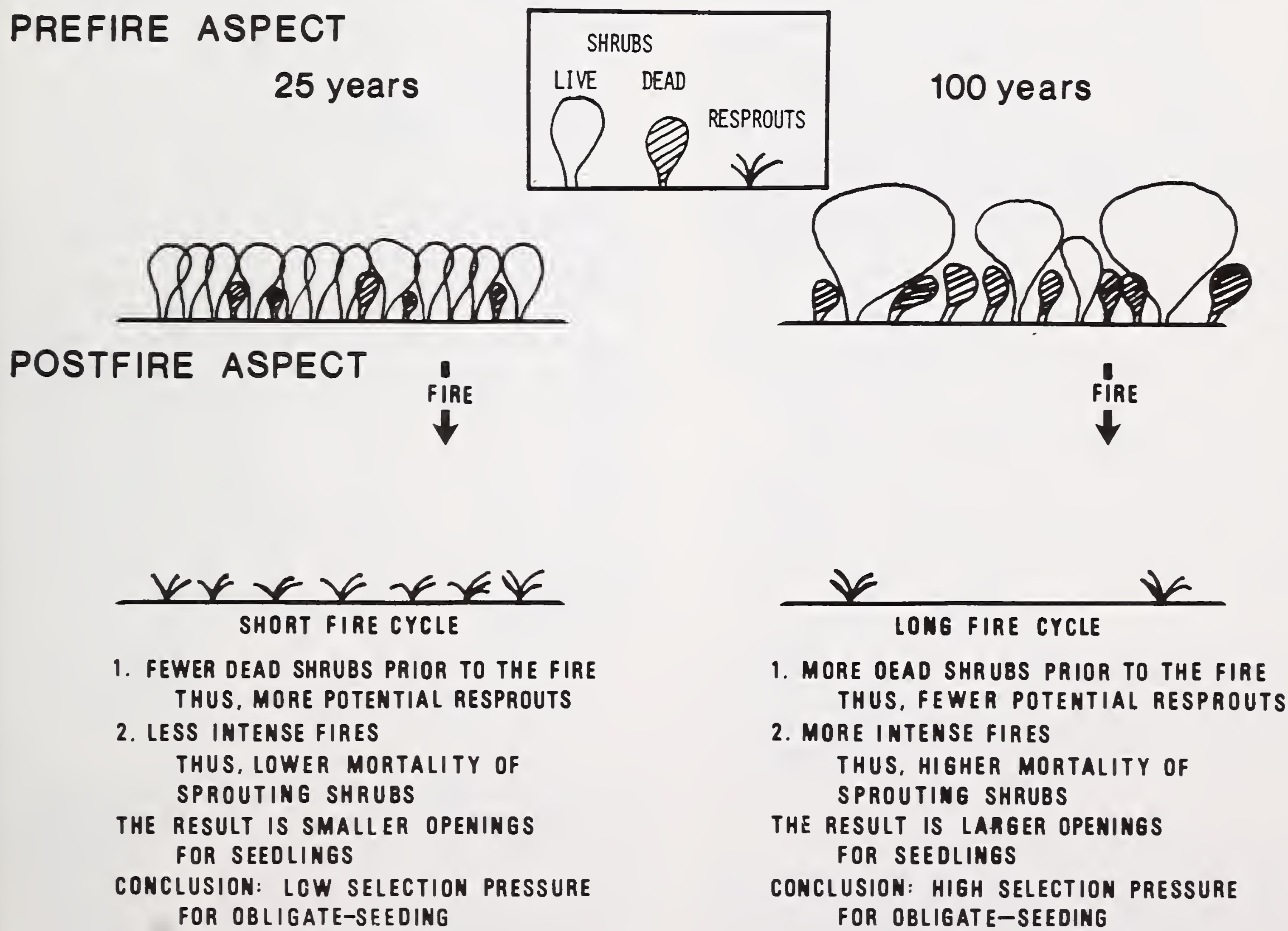

Figure 2--Model of the relationship between successional changes in the density of live shrubs and relative abundance of postfire resprouting shrubs resulting from fires early vs. late in succession.

For want of a better name I shall call this the "Stochastic-Fire Hypothesis." If we consider a prehistoric chaparral environment composed entirely of sprouting species then the size of postfire openings will be highly dependent upon the frequency and intensity of fires in the environment.

In this pre-hominid environment lightning is the only significant source of fires and these fires are randomly distributed both in time and space. The result is that any given area of chaparral has a high probability of an occasional short period of time between fires and an occasional long period of time between fires. Since obligate-seeders depend upon building up seed pools in the soil the shorter the period between fires the greater the advantage is to sprouters. However, occasional extended periods of time between fires should work the other way, i.e., favor seeders over sprouters.

There are several reasons for this. Seeds of chaparral shrubs are adapted to surviving very long periods of dormancy. In fact there is little difference in the number of seedlings after fires in 100-yr-old and 20-yr-old chaparral (Keeley and Zedler 1977). Sprouting species on the other hand are at a distinct disadvantage the longer the fire-free period. The reasons are two-fold. One, during succession there is a constant thinning of shrubs. As the length of the fire-free period increases, shrub size increases so that individual shrubs appropriate a greater amount of space at the expense of neighboring shrubs. The result is a reduction in the density of potential resprouts. Second, as the stand of chaparral matures there is an accumulation of dead fuel which contributes to a more intense fire the older the stand of chaparral becomes. Thus, the longer the fire-free period the larger the openings after fire (fig. 2). This hypothesis suggests that occasional, long fire-free periods (e.g., 100 yrs or more) have been an important evolutionary stimulus for the obligate-seeding strategy.

What predictions can we deduce from this hypothesis? One prediction is that the abundance and diversity of obligate-seeding species should increase inversley in relation to the frequency of natural fires in the environment.

A TEST OF THE HYPOTHESIS

This is a very difficult prediction to test since the present temporal and spatial pattern of fire is man-made; e.g., in southern California man is responsible for nearly 99% of all acreage burned and he is also responsible for extinguishing a great many lightning fires.[4/] As an example, at the present time in southern California forests the quivalent of the total acreage of these forests is burned by man ca. once every 50 yrs; by lightning it's once every 4000 yrs. Suffice it to say we do not know what the natural pattern of fire is in chaparral. To even approach this goal would require a large scale modeling effort (e.g., Hobbs 1974).

However, there are data available on the frequency and distribution of lightning fires in chaparral regions. Although the number of lightning fires is not a definitive measure of the natural fire frequency it at least tells us something about the relative spatial pattern of natural fires. Explicitly this assumes that a lightning fire in one location is equivalent to one in another area. This certainly will not be the case, due to variations in burning conditions, but it should provide a reasonable first approximation.

Data from Court (1960) and Komarek (1967) provide an overview of lightning fire patterns in California. These data show three distinct patterns. Lightning fire frequency decreases

1) from northern to southern Calif. (fig. 3)
2) from medium-high to low elevation
3) from the interior to the coast

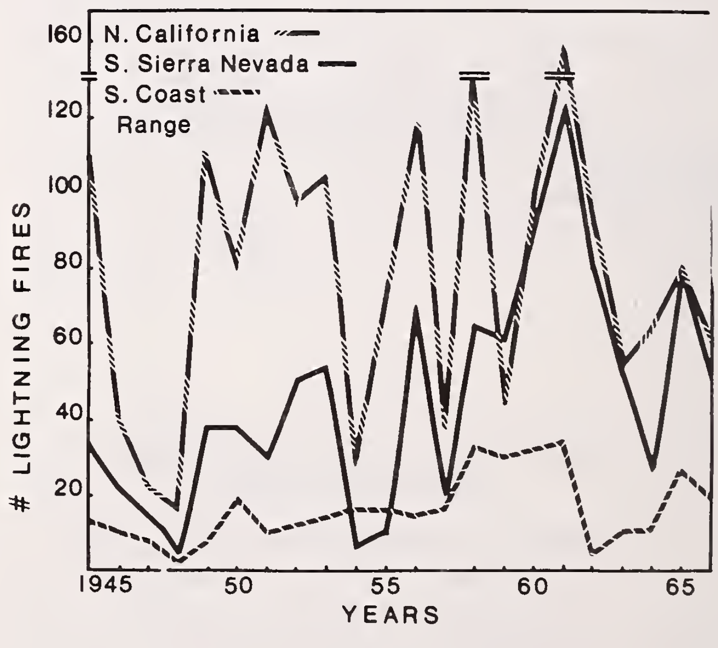

Figure 3--Lightning fires on National Forests of northern California, southern Sierra Nevada and southern Coast Ranges (from Komarek 1967).

4/ All fire statistics for southern California are from unpublished fire dispatcher data on statistical fires for the Los Padres, Angeles, San Bernardino (1965-1974), and Cleveland (1960-1974) National Forests.

Focusing on southern California we see these last two patterns repeated; a high correlation between # of lightning fires and elevation (r_s= 0.71, P <0.01), and the more interior forests have higher frequencies than coastal ones.

Table 1--Lightning fire statistics for southern Calif. Nat. Forests (see footnote 4).

District		Mean Elevation m	(ft)	#/yr	ha/yr
LP:	Mt. Pinos	1700	(5800)	10.9	72
	Santa Lucia	985	(3230)	1.9	11
	Ojai	1620	(5340)	.9	2
	Santa Barbara	975	(3200)	.6	9
	Monterey	1615	(5300)	1.9	2
A:	Valyermo	1890	(6190)	8.1	< 1
	Mt. Baldy	1895	(6220)	2.2	2
	Arroyo Seco	1490	(4880)	3.2	< 1
	Tujunga	1520	(4990)	3.6	2
	Saugus	1070	(3520)	.7	< 1
SB:	San Jacinto	1795	(5890)	17.1	8
	San Gorgonio	2665	(8740)	18.3	192
	Big Bear	2145	(7130)	19.9	27
	Arrowhead	1760	(5780)	6.9	< 1
	Cajon	1850	(6070)	3.3	< 1
C:	Palamar	1320	(4330)	7.3	158
	Descanso	1220	(4000)	3.9	13
	Trabuco	885	(2900)	.7	< 1

Based on these data there are two clear predictions. Comparing for example the Sierra Nevada and southern California, I would predict that 1) nonsprouting Ceanothus and Arctostaphylos would be most extensively developed (in diversity and abundance) in southern California and 2) within each region the abundance of nonsprouters would be highest at the lower elevations whereas the peak abundance of sprouters would be higher.

To test these predictions data was taken from Critchfield (1971); a compilation of > 10^7 ha of line transects illustrating the dominant vegetation of California. From each of these vegetation profiles the length of transect occupied by sprouting and nonsprouting Ceanothus and Arctostaphylos was recorded (Table 2).

Table 2--Relative cover and # of species for Ceanothus and Arctostaphylos, by region.

	NONSPROUTERS Transect (km)	# Sp.	SPROUTERS Transect (km)	# Sp.
SIERRA NEVADA	265	7	274	6
SOUTHERN CALIFORNIA	868	25	333	7

There is certainly no question that the first prediction is upheld; the highest diversity and greatest abundance of nonsprouting species is in southern California. The second prediction (fig. 4) is also confirmed. The abundance distribution of nonsprouting shrubs is centered around the lower elevations and the sprouting shrubs at the higher elevations. Thus, the region with the lowest lightning fire frequency is the southern coastal ranges; this is also the area which supports the greatest abundance and diversity of nonsprouting species. In contrast the mid-elevation range (2000 m) of the Sierras is a region with a very high lightning fire frequency and the chaparral of this area is quite depauperate in nonsprouting species.

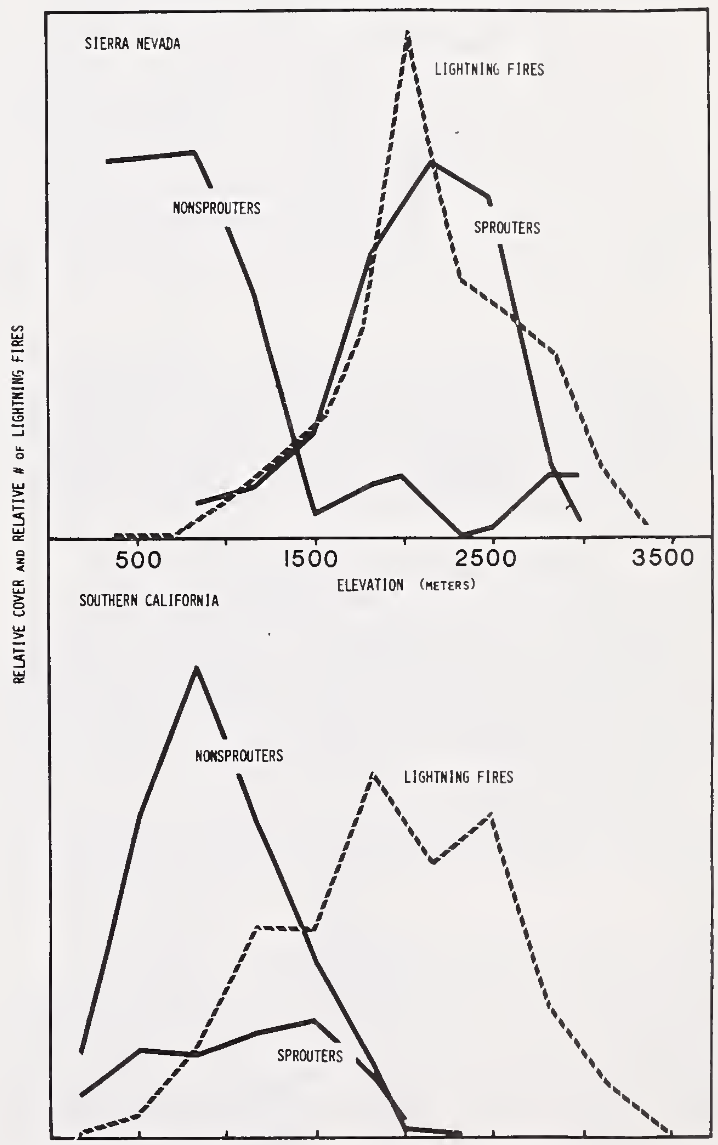

Figure 4--Relative shrub cover and relative # of lightning fires (Sierra Nevada lightning fire data from Komarek 1967).

One of the important conclusions from this hypothesis, particularly from a management perspective, is that the real selective pressure for the obligate-seeding strategy may have been the unpredictability (and consequently the occasional infrequency) of natural wildfires in the southern California chaparral. I would

envision an environment in which fire is inevitable but one in which, for any given patch of chaparral, there is a high probability of an occasional fire-free period for as long as a century or more.

Some may grimace at the thought of southern California chaparral having evolved under periodic long fire-free periods, however it is not an untenable hypothesis. Many of the coastal fire districts, which cover hundreds of thousands of hectares, have fewer than one lightning fire a yr. Generally these are accompanied by rain and it is likely that many would burn themselves out if given the chance. This is supported by the fact that there is a significantly greater # of lightning fires put out by the Cleveland National Forest Service today than 40 yrs ago ($\mu_{1935-1949}=6.3$/yr is less than $\mu_{1960-1974}=11.9$/yr by the Mann Whitney U-test, $P < .02$). I interpret this to mean that 40 yrs ago many lightning fires were allowed, knowingly or unknowingly, to burn themselves out and would do so today if given the chance.

A rejoinder to this argument would be that "a little fire can go a long way, particularly in chaparral." Witness for example the great fire holocausts such as burned much of San Diego Co. in 1970. These fires, however have two factors in common. Almost invariably they occur during Santa Ana (low humidity, high velocity foehn wind) conditions and they result from human ignition. It's questionable whether or not this sort of wildfire was a very frequent occurrence in the pre-hominid chaparral environment because lightning fires seldom occur even in the same month as Santa Ana conditions (fig. 5), let along in concert with those conditions.

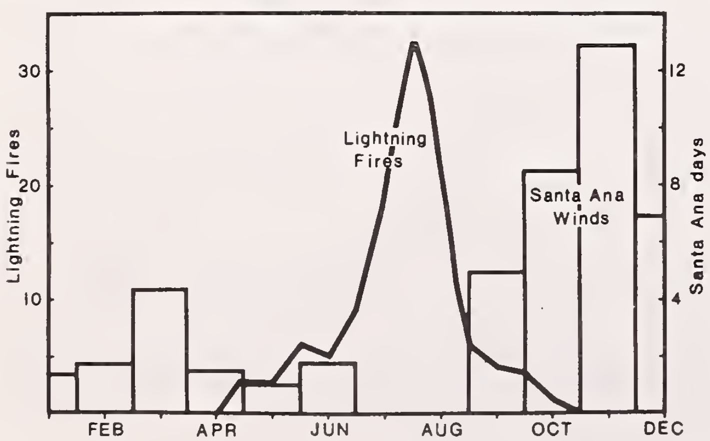

Figure 5--Monthly distribution of lightning fires and Santa Ana winds in southern California (10 yr ave). Santa Ana data from Weide (1968).

In conclusion, two caveats are in order. One is that the hypothesis for the origin of the obligate-seeding strategy is only one of several tenable hypotheses; it is offered in that light. A second is that the arguments proposed here are not meant to play down the importance of fire in the chaparral environment, rather to emphasize the potential evolutionary importance of the unpredictability of fire in this environment. The management implications are manifold and certainly deserve future consideration.

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PRESCRIBED BURNING PROGRAM FOR THE COASTAL REDWOODS AND CHAPARRAL[1/]

Jason Greenlee[2/]

Abstract: Implementation of a fire management plan using prescribed burning on the University of California, Santa Cruz, campus was preceded by an evaluation of the existing fuel break system, a computerized fuel inventory, trial plots to test prescriptions, and the writing of a management plan. In this report, a consultant describes the process, gives his burn prescriptions for redwood (Sequoia sempervirens) forest, chaparral and broad schlerophyll forest, and discusses the costs of the operation.

Key words: fire hazard reduction, fuel inventory, fuel management, fire prescriptions, prescribed fire costs.

INTRODUCTION

A burn prescription is a tested prescription of fuel and weather conditions that permits the application of controlled fire to wildlands for a multitude of purposes. It employs fire scientifically to maximize net benefit to vegetation, wildlife and fire hazard reduction with the minimum damage and risk and at an acceptable cost.

A prescription for the use of fire to manage wildlands has recently been developed for the University of California, Santa Cruz (UCSC), campus. Implementation of the prescription is now in an early stage. In this paper, I will relate how I set up the system, as well as some of the needs of a small fire management program.

Forest fire management is a developing technology that includes fire prevention, fire hazard reduction and fire suppression. In California, emphasis is increasingly shifting to the first two of these efforts: public education; cessation of woods operations in times of high fire danger; fuel break construction; fuel break maintenance; fuel modification; and fuel removal have been shown to be effective in reducing the occurrence and severity of forest fires despite growing human populations in rural areas.

Decisions in forest fire management involve social, economic and feasibility criteria; these conditions are of fundamental importance to the success of a fire management plan.

FIRE MANAGEMENT ON A SMALL SCALE

The university campus is in the north part of the city of Santa Cruz on the central California coast south of San Francisco. Elevation on the 800 hectare campus varies from 90 to 365 meters. A complex vegetation of coastal redwood (Sequoia sempervirens), broad schlerophyll forest, chaparral, and grasslands overlie sandstone, schist and limestone substrates (fig. 1)

Not having burned since early in the 1900's, the campus has fuel loadings as high as ninety thousand kilograms per hectare in some chaparral areas. The redwood forest and particularly the broad schlerophyll forest also have heavy accumulations of fuels which form a ladder into the forest canopies.

As the campus buildings only occupy a small portion of the property, much of the campus is being managed something like a park. Management objectives on these areas of only dirt-road access include fire protection, preservation of the vegetation's naturalness, but the primary objectives is recreation. Unfortunately, these objectives are not always compatible.

1/ Presented at the Symposium on Environmental Consequences of Fire and Fuel Management in Mediterranean Ecosystems, Palo Alto, Calif., Aug. 1-5, 1977.

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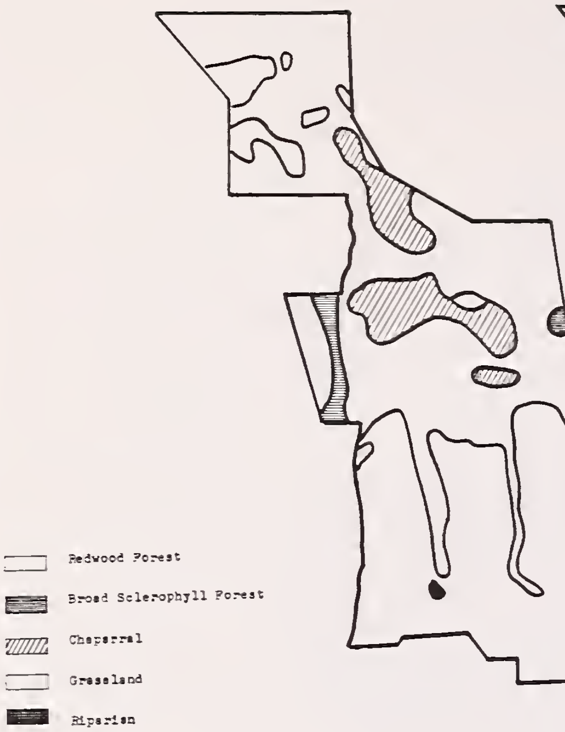

Figure 1--Vegetation map of the University of California, Santa Cruz (UCSC)

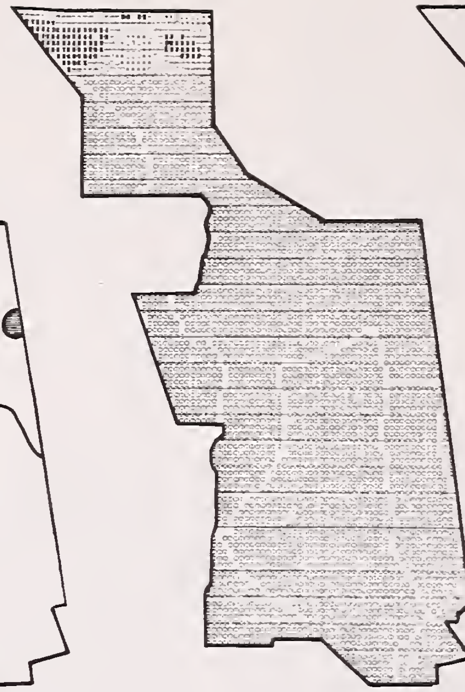

Figure 2--Computer-made fuel map of UCSC. Upper portion of the map is completed.

Figure 3--Phase 1 of the prescribed burn plan for UCSC. This phase burns over previously established fuel breaks.

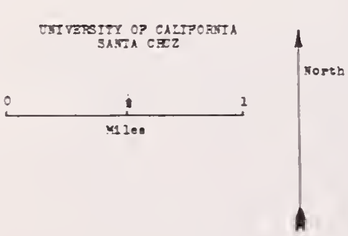

Figure 4--Phase 2 of the prescribed burn plan for UCSC. The completed Phase 1 is shaded.

Figure 5--Phase 3 of the prescribed burn plan for UCSC. The completed Phases 1 and 2 are shaded.

Figure 6--Phase 4 of the prescribed burn plan for UCSC. The completed Phases 1, 2 and 3 are shaded.

After the founding of the campus in 1964, a fuel break system was constructed. This system extends north and south along the long axis of the campus and east and west across the narrow waist of the campus (fig. 3). The system was designed so that a wildfire coming from the north would be stopped before burning into the central campus building area. The purpose of my work at Santa Cruz was to develop a prescription for burning on the campus, and to establish a fire management system compatible with the management objectives of the campus. I have followed a six phase plan:

1. Evaluate the present fuel break system.
2. Establish the support systems needed to develop a prescribed burning program (weather monitoring, computer and fuel inventory systems).
3. Inventory the fuels on campus.
4. Create test plots for each major fuel type to develop a prescription for burning them.
5. Develop a management plan, have it approved, and initiate its first steps.
6. Train campus employees in the functioning of the system, so that it could be self-maintained.

THE MANAGEMENT PROGRAM

It is always necessary to first establish what fire management system is best for a given unit of land. Hence, the first task I undertook was to research the costs and benefits of the fuel break system that I was to augment. Cost of the university's previous fire management program were as follows:

1. Fuel Break Construction (manual), involving an area of 56 hectares, cost $3,700 per hectare.
2. Fuel Break Maintenance
   a. Mowing, involving 25 hectares, cost $280 per hectare a year.[2/]
   b. Manual, involving 32 hectares, cost $100 per hectare a year.[3/]
3. Fuel Reduction Between Fuel Breaks (manual), approximately 240 hectares, cost $1,000 per hectare.
4. Fuel Reduction Between Fuel Breaks Maintenance (manual), approximately 240 hectares, cost $100 per hectare a year.[3/]

Twenty five hectares of the fuel break can now be maintained by tractor mower. If the campus elected to attempt fuel reduction between the fuel breaks, the estimated costs using hand crews would be $1,000 per hectare initially, and then $100 per hectare per year of maintenance.[3/] These figures looked favorable to me, because I felt that prescribed fire could be used to reduce fuels at costs significantly lower. I then felt justified in spending some money; I bought three weather stations, a teletype machine, some computer time, drip torches, a fuel moisture gauge, fire fighting tools, and a flame thrower.

One main weather station was installed in a clearing behind the campus fire station. Daily weather readings are fed into a U.S. Forest Service computer program in Cincinnati via teletype. Using this system, National Fire Danger Ratings (Deeming et. al. 1974) are received daily for less than $1 per day (less than what it would cost to compute the ratings by hand). These indices have two functions: first, they indicate the fire danger on any particular day; and, second, they are used in conjunction with prescription burning experiments, and will eventually become part of the prescription.

Fuel Sampling

A fire manager must know what the fuel situation is on the management unit. Thus, the next step was to decide how to sample fuel loadings on the campus. Brown (1974) has developed a technique for sampling downed woody fuels, such as logging slash. His sampling system was modified somewhat to meet our specific requirements, and is now being used to sample the redwood forest and broadleaf schlerophyll portions of the campus.

The chaparral areas are giving us some problems, however. Brown's technique, which is not intended for chaparral, underestimates chaparral loadings by a factor of two. Although we are testing some other sampling techniques, we are temporarily restricted to simply cutting and drying a small plot to determine the loading.

A computer program was written to calculate fuel loadings from Brown's modified technique. The following are outputs from this program:

1. Fuel loading of downed woody material by fuel size class (Brown's technique)
2. Number of live stems by species, stem size and basal area.
3. Number of dead stems by species, stem

[2/] One-year maintenance cycle.

[3/] Ten-year maintenance cycle.

size and basal area.

4. The ratio of dead to alive stems in the canopy.
5. Average duff depth.
6. Average fuel depth.
7. Fuel volume for each size class.
8. Vertical continuity of fuels from the ground to tree canopy.
9. Crown fire potential (subjectively determined index of vertical pattern).
10. Spread potential (subjectively determined index of horizontal pattern).

Fuel data, once calculated, are put into a second commerically available SYMAP program (Dudnik, 1972), which displays the fuel loadings for each sample site on a computer-made map (fig. 2). The purpose of the maps is to eliminate the abstract fuel loading estimates normally used by manager and to make these data site-specific. In this way, particularly high fuel loadings can be identified as actual geographic sites.

The computer maps are able to periodically update the fuel loadings through growth factors given the program. Information on site manipulation can also be fed into the machine to update the map. Both the fuel program and the SYMAP program control cards are available to other managers on request.

The Burn Prescription

Designing an experiment to determine the proper prescriptions for each of the campus fuel types (redwood forest, schlerophyll forest, chaparral, and grassland) was the most challenging part of setting up a fire management program using prescribed fire. The variables of most interest were method of pretreatment, season of burning, fuel stick moisture (moisture content of dead wood), method of firing (headfire versus backfire), and the optimum size of a burn. Relative humidity, wind speed, and temperature were not varied experimentally, but were kept within prescribed thresholds (Green and Schimke 1970).

Vegetation that has not burned for many decades, often needs treatment prior to its first burn. In the redwood and broad schlerophyll fuel types, the greater portion of the fuels are of small sizes: leaf litter and small branches. As this cannot be cut, removed or chipped, the best type of pretreatment is a light fire to burn away some of the lighter fuels in the understory. Another fire can follow to clean away the remaining fuels and the smaller plant stems killed by the first fire.

The chaparral fuel type, however, must be pretreated by cutting the stems at ground level and allowing a drying period of two weeks before burning. We have had success using a machine to cut the chaparral before burning.

The season of burning will have an effect on the seed versus sprout response of the vegetation and thus on wildlife forage. Biswell (1974) notes that no sprouts appeared in a mid-August chaparral fire in southern California until the following spring. Gibbens and Schultz (1963) note that in California fuel burning favors seed reproduction of non-sprouting chaparral plants, while late spring burning favors sprout reproduction of sprouting plants. As nearly all campus chaparral plants are sprouting species, chaparral burns on UCSC are in the spring.

Season of burning is also important to the safety of the operation. In areas subject to crown fire, such as in the broad schlerophyll forest, it is safer to burn in the spring when vegetation is not too dry, and strong desert winds are not so frequent (Biswell 1974). Areas with heavy fuel loading or ladder fuels should be burned in the spring. Areas that need pretreatment by fire could be burned in the spring and then again the following fall or spring, depending on the hazard involved. I have used fall burning in the redwood fuel type, in areas where the fuel loading is not too high.

The strategy for testing prescriptions on the campus was to establish a line of test plots of 100 square meters in each fuel type. Each plot was burned at a different fuel moisture, beginning with the most moist fuel condition that would carry a fire. This moist fuel condition was determined by weekly attempts at burning after the last winter rain. When conditions for burning were met, usually at fourteen or fifteen percent fuel moisture, testing would begin. Further drying periods would then be allowed, and the remaining plots would be burned at progressively dryer stages, until unsafe burning conditions were met. In this way, the optimum fuel moisture for burning each fuel type could be found in the midrange of these plots.

Whether the plot is burned with the wind (or uphill--headfires in either case) or against the wind (or downhill--backfires in either case) is another important variable. The test plots were therefore replicated to test both methods. In this way, a redwood plot might be burned at seven percent fuel moisture with a headire, and at seven percent fuel moisture with a backfire. Notes and photographs are used to record fire behavior.

We are raking litter away from the base of trees to avoid scorched bark. I have found that redwood trees that have not been burned previously will scorch easily. Although raking raises costs, the campus administration feels strongly about the aesthetic impact of scorched bark. To reduce cost, I do not use a large crew to mop-up a fire, but merely use the skeleton crew that is always necessary to watch the fire until it is out. This unusual practice is made possible by the moderate weather conditions used in prescribed burning.

On the small chaparral test plots, very heavy deer browsing was noted on the returning sprouts. As the area of test burning was only 100 square meters, the deer concentration could easily be high enough to prevent sprouts from achieving any growth, and the plants may eventually be killed. For example, a 100 square meter burned plot had no emergent coffeeberry (Rhamnus californica) or oak (Quercus wislizenii) sprouts, while manzanita (Arctostaphylos glandulosa) sprouts, which were not being browsed, were one meter tall after one year.

This point brings out the question of how large a prescribed fire should be in each fuel type. Several factors play into this decision. Size of the management unit, aesthetic requirements and wildlife ecology should all be weighed. A chaparral burning policy should aim at creating a patchwork mosaic of small burns of various ages, the wildlife using each age class for a different purpose (Biswell 1969). Because the objectives on campus are primarily preservation and recreation, small fires spread out on the campus are preferred over large, unsightly burns. An administrative decision was therefore made to keep redwood burns under four hectares, although several prescription fires could be done each year. In the chaparral, the size of each burn is kept under two hectares.

Table 1 is a synopsis of the tentative prescriptions for the fuel types on the university campus. Grass is not included here, as these tests are not yet completed.

With the tentative burn prescriptions prepared, larger scale burns have been planned. Data continue to be collected on these burns to refine and fill out the prescriptions. The campus plan first calls for the burning of the fuel breaks created ten years ago (fig. 3), followed by the burning of areas between the breaks (fig. 4). Finally, outlying areas may be burned (fig. 5 and 6). The burn plan calls for intense activity for several years, leading to the completion of my consulting contract. At that time, burning will become a yearly maintenance operation.

Public Relations

Fire managers must pay close attention to public relations. In the case of UCSC, which is in a suburban area directly in view of townspeople, it is imperative to work closely with concerned agencies and with the media. Students, faculty and public are given informational slide-shows and are walked around the burn sites in an effort to educate them about fire management and to get their input into the program. The campus fire department, police and public relations offices all participate in the burn operations, and an academic committee must approve each burn.

This machinery works well, with a few excpetions. On the 13th of October 1976, I was burning a redwood study plot when a green Department of Forestry sedan pulled up. A friend of mine from several years climbed out and requested that I call a local radio station and tell them that the Department of Forestry was not up here on the campus burning illegally on a no-burn day; that I was the one burning illegally. I thought this misinformation deplorable, and went to a phone. When I called the station, I found that matters were worse than I had thought. The station manager had called the local air pollution office to ask

Table 1--Tentative prescriptions for the University of California, Santa Cruz.

	Fuel Type			
	Chaparral	Redwood	Redwood	Broad Schlerophyll
Pretreatment	cut & dry	n/a	n/a	n/a
Season	spring	spring	fall	spring
Fuel Moisture	10-11%	9.5%	11%	10%
Wind Speed	0-15 kmph	15-25kmph	15-25kmph	0-15 kmph
Temperature[1/]	7-29° C	7-29°C	7-29°C	7-29°C
Relative Humidity[1/]	26-64%	26-74%	26-64%	26-64%
Method	backfire	headfire	backfire	headfire
Size	2 ha.	2-4 ha.	2-4 ha.	2-4 ha.

[1/] Schimke and Green, 1970 (converted to metric units).

about my burning on an announced no-burn day, and was told that I had no permit and that I was going to be cited. I had, in fact, gotten my permission to burn that day directly from the Sacramento Air Resources Board. Unfortunately, Sacramento had neglected to notify the local board, as was their duty. The resulting squabble ended in a stalemate, with both sides having learned a good deal. My lesson was that public and agency relations are extremely important; on the following burn, two television stations and three newspapers were invited to attend. Such is burning in the big city.

Costs of Prescribed Burning

The following are burning costs for the University of California, Santa Cruz, fire management program:

Two Year Research Stage	
a. Consulting fee	$ 8,000
b. Equipment (weather stations, computer terminal, computer time fire fighting equipment)	$11,466
Subtotal	$19,466
Implementation Stage	
a. Redwood burns (2-4 hectares)	$185/ha.
b. Chaparral burns (2 hectares; includes machine cutting of chaparral as pretreatment)	$407/ha.

These costs are higher than necessary because our burns are small and manpower is double what is needed for safety purposes. Experience will undoubtedly bring costs down. The chaparral costs cannot be reduced greatly, however, because the set cost of hiring a machine cutter is not going to go down with experience.

Future Needs

In discussing the needs of small scale prescribed burning operators, the first thing I would like to call attention to is the need for more cooperation between fire managers. Standard record keeping is a must for this developing science. Records of burning conditions, and observations of effects of the burn need to be standardized, so that any fire manager can look at the work being done across the country.

All fire management people, government and civilian alike, are sorely pressed for adequate fuel sampling techniques; they just don't exist. Much work needs to be done, particularly on a technique for sampling fuel loading of chaparral. Both remote and site-specific techniques are needed.

The National Fire Danger Rating System needs to be improved. At the moment, fire managers over the country have only eleven fuel models from which to choose a model that represents their fuel conditions. In view of the enormous variability of fuels in the nation, a more flexible modeling system is needed.

Fire managers should pay more attention to the lessons learned by myself and other unfortunates in the area of public relations. At this time, most urban dwellers would still over-react to the sight of low flames playing at the base of a tree.

Finally, a credential system is needed for fire managers with some criteria set for minimum qualifications. The federal government might pave the way for such a system by opening fire fighting and fire management schools to any agency or civilian desiring to attend.

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A CASE STUDY OF FUEL MANAGEMENT PERFORMANCES, ANGELES NATIONAL FOREST, 1960-1975[1/]

Philip N. Omi[2/]

Abstract: The performances of preconstructed firebreaks and fuelbreaks during the period 1960-75 are analyzed within four damage-potential zones established for the Angeles National Forest. The multiple regression analysis of past performances suggests that the association between preconstructed breaks and reductions in area burned may not be as strong as suggested in the analyses which are used to justify future fuel management projects.

Keywords: Firebreak, fuelbreak, fuel modification, fire management planning.

INTRODUCTION

Recurrent large losses from disastrous wildfires in southern California have emphasized the need for an integrated fire management program. One response of the Angeles National Forest to its unique wildfire problems has been the construction of an extensive system of firebreaks and fuelbreaks in selected, strategic locations. A firebreak is distinguished from a fuelbreak in that the former is generally narrower and kept clear of vegetation. On the other hand, a fuelbreak on the Angeles National Forest has a minimum width of 40 meters (100 feet) and may be intentionally planted to a low volume fuel, such as perennial grasses

OBJECTIVE

The objective of this study is to provide a systematic framework for analyzing and planning future investiments in fuelbreak construction and maintenance on the Angeles National Forest. This study consists of two parts. In part one, estimates of productivity were derived for firebreak and fuelbreak systems during the period 1960-75. Part two (in progress) relies on these productivity estimates and the best judgment of fire managers to test multiyear allocation schemes for fuelbreak construction and maintenance alternatives.

STUDY AREA

The Angeles National Forest consists of 272,000 hectares (691,000 acres) of forest and chaparral lands, mostly within Los Angeles County. The land encompassing the National Forest was originally set aside in 1891 as the San Gabriel Timberland Reserve for the purpose of protecting the watershed provided by the San Gabriel Mountains.

Despite a general lack of objective criteria by which fuel management programs may be evaluated, the Angeles National Forest has long been committed to a program of firebreak and fuelbreak construction. Based on current inventories, approximately 5,915 hectares (14,610 acres) of fuelbreak and 4,068 hectares of firebreak exist on the Forest. Of these totals, roughly 50% of the fuelbreaks and 10% of the firebreaks were constructed after the 1970 fire season. The fire losses incurred that year served as a catalyst for securing

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accelerated levels of funding for fuel management programs on the four southern California National Forests.

STUDY DESIGN AND RESEARCH METHODS

Zones Within the Forest

The basic units of analysis are the 71 fire damage appraisal units comprising the Angeles National Forest (Buck, Fons, and Countryman 1948).[1] As depicted in figure 1, each unit consists of the upstream portion of a single stream or tributary, or a major slope facet within the National Forest.

The 71 units were placed into four groups, hereafter referred to as fire damage-potential zones, based on multivariate clustering techniques. Table 1 presents the attributes measured on each unit and which were utilized in the clustering process. Each attribute was assumed to represent a contributory influence upon the long-term damage-potential of a single damage appraisal unit, based upon literature review and my discussions with watershed scientists and fire managers.

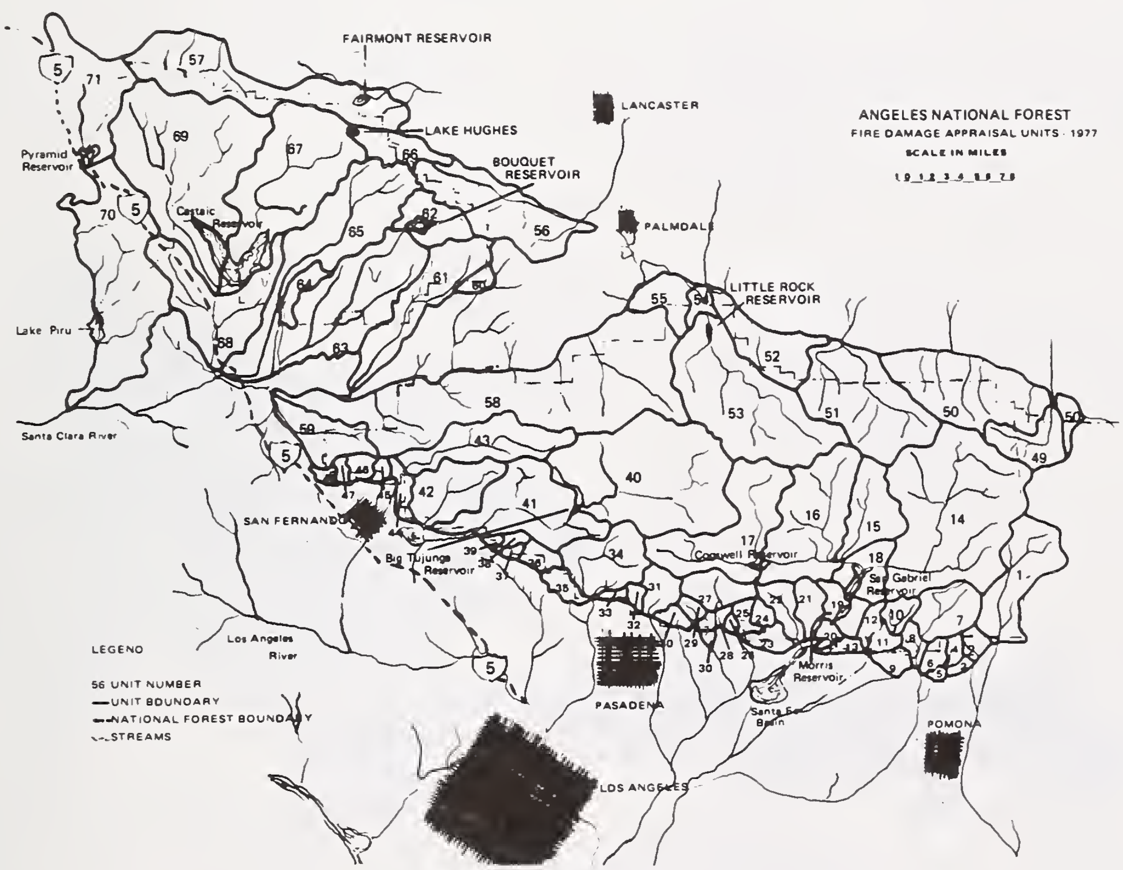

Figure 1--Fire damage appraisal units comprising the Angeles National Forest (adapted from Buck, Fons, and Countryman 1948).

[1] The 1948 study identified only 70 units. For purposes of this study, an additional unit was created to separate the upstream and downstream portions of the recently constructed Pyramid reservoir in unit A-70.

Table 1--Drainage basin attributes measured for grouping damage appraisal units into damage-potential zones.

ATTRIBUTE	UNITS OF MEASURE
1. Location coordinates	Degrees (lat., long.)
2. Relative areas occupied by different aspect-elevation zones	Percentage of total area x 100
3. Available sediment production area (Total area minus reservoir area)	Hectares
4. Drainage basin steepness (Relief ratio = gradient in elevation / longest dimension of drainage basin)	Unitless x 1000
5. Drainage density (Total length of major drainage channels / total area)	Kilometers/hectare
6. Average and range of 90-year precipitation	Centimeters
7. Drainage basin geology and soil dispersion properties (Index of erosion hazard by parent type, weighted by areal distribution of parent types)	Unitless
8. Fault density	Kilometers/hectare
9. Unimproved road density	Kilometers/hectare
10. Proportion of drainage basin occupied by high urban or recreation potential	Percent x 100

Sample Fires

The division of the Forest into the four damage-potential zones automatically established four unique populations of fires for analysis. It was postulated that each zone supports a unique range of long-term fire environments, even though the fires in a single zone might vary considerably in behavior and effect over an extended time period. The fires which encountered breaks or which attained size greater than 40 hectares during the period 1960-75 were assumed representative of all fires which grow to that size and are subjected to the unique environments within each zone.

Establishing Firebreak and Fuelbreak Productivity Estimates

A multiple regression analysis was conducted in each zone to establish the overall association, if any, between constructed breaks and the expected area (in hectares) of sample fires. The analysis evaluated the performances of individual fuelbreak and firebreak segments on the sample fires. A distinction was made between encounters which took place at boundaries between damage appraisal units (generally major ridgelines or canyon bottoms) and those occurring wholly within a single unit (secondary ridgelines or lateral to unit boundaries). The major

ridgetop or canyon bottom is usually of higher strategic importance in checking the forward momentum of fire spread and in providing firefighter access. Past fire encounters with unit boundaries were designated as primary encounters. Where present, a break was designated as a primary firebreak or fuelbreak. From the standpoint of assessing break effectiveness of unit boundaries, it was important to also include the expected area burned where there had been no fuel management. For if fires were repeatedly controlled in the absence of breaks, the necessity of break construction must be questioned.

Encounters with breaks located on secondary ridgelines or laterals were referred to as secondary encounters. No distinction was made between lateral breaks and those existing on secondary ridgelines or canyon bottoms, which, for purposes of the analysis were considered of comparable importance to fire management strategies for confining fire damage to the unit of origin.

RESULTS

Figure 2 portrays the fire damage-potential zones within the Forest, hereafter referred to as the Front, Mid-main, Transition, and Desert Front zones. These zones contain respectively forty, eight, thirteen, and ten of the original seventy-one fire damage appraisal units.

Units belonging to the Front damage-potential zone drain into the Los Angeles, San Gabriel, and Santa Ana rivers. Steep slopes of high relief rise abruptly out of the densely populated areas of the metropolitan Los Angeles area, creating some of the highest levels of potential fire and flood damage to be found anywhere.

The Mid-main damage-potential zone forms the backbone of the San Gabriel mountains. High average rainfall levels, including snow on ridgetops which rise to 3050 meters (10,000 feet), charge the network of drainage channels within these large basins.

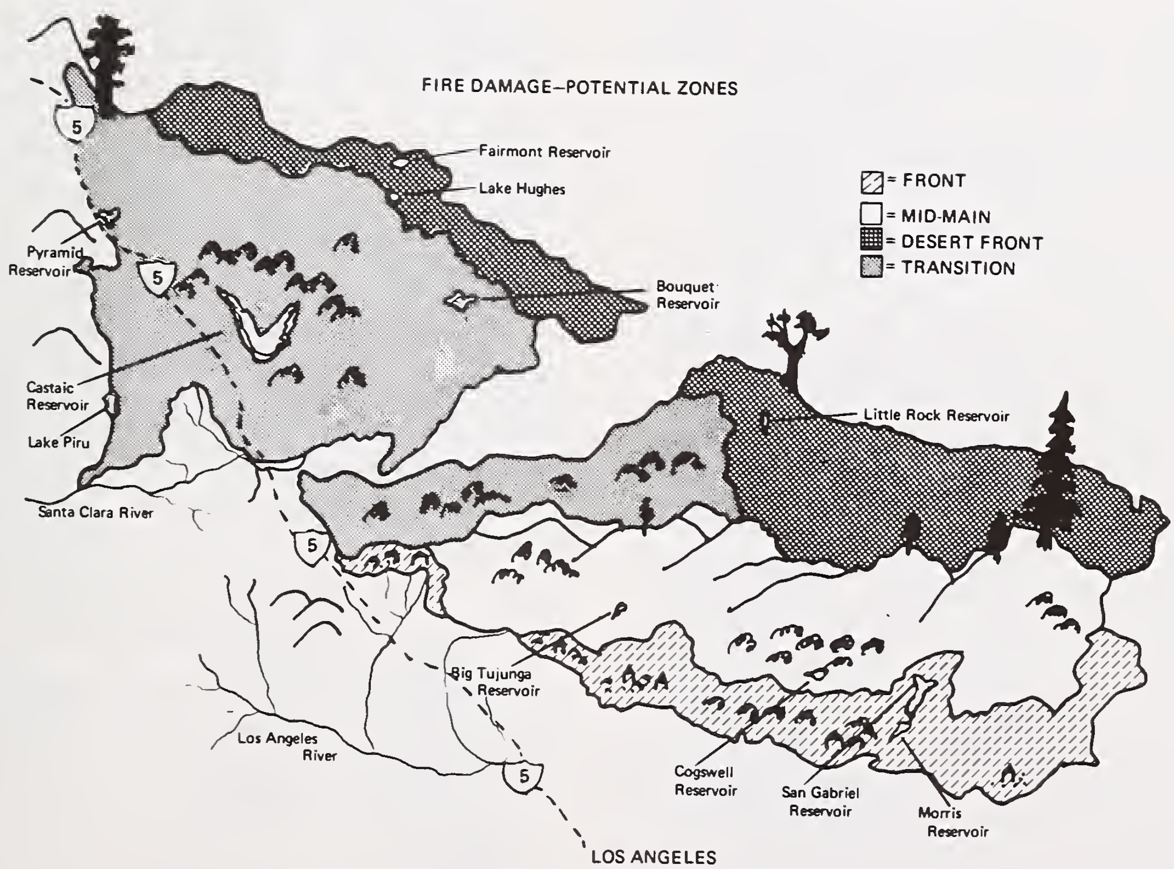

Figure 2--Fire damage-potential zones, Angeles National Forest.

The thirteen units comprising the Transition damage-potential zone all drain into the Santa Clara River basin. This zone is transitional in two respects, lying as it does between high elevation mountains in the Coast Range and the high desert to the east, while to the south lies the Greater Los Angeles basin. These areas support high recreation values due to the presence of large reservoirs. Increasing urban values due to suburban development have accentuated the need for higher levels of fire protection investments in recent years. In general, the slopes in this zone are less steep and more amenable to fuelbreak construction.

The damage appraisal units which overlook the Mojave Desert form the Desert Front damage-potential zone. These units are generally high in elevation with predominantly northern aspect. Low average rainfall produces a sparse vegatative cover and discontinous fuelbed.

Break Performances

The analysis postulated a relationship between the area burned beyond break encounter and the presence of preconstructed firebreaks and fuelbreaks, fire behavior severity as measured by the daily Burning Index of the National Fire Danger Rating System (Deeming et al 1972), suppression resource availability under multiple fire situations, and fuel age.

The dependent variable in the analysis was a measure of area burned, subject to a logarithmic transformation. The transformation stabilized variances and also compensated for the expected nonlinearity of fire effects under extreme burning conditions. The measure of success utilized for a particular fuelbreak or firebreak segment was the area burned beyond encounter. This variable ranged from near zero, if the fire was stopped, to some large positive number, if the fire spread into adjoining watersheds.

A slightly different construct was utilized in the analysis of secondary encounters. Of interest was the total area burned within the unit of origin. If initial attach is unsuccessful in keeping a fire small, fire managers may redirect their attentions to confining the fire's spread to the drainage basin of origin. The role of secondary breaks were examined in this context as opposed to the role which they might play once the fire had escaped to an ajoining watershed.

The following equations resulted from systematic experimentation with different combinations and transformations of independent variables within the Front, Mid-main, and Transition zones respectively:

$$\ln Y = .76 - .01\,\text{FIREBRK} - .05\,\text{FUELBRK} + 1.55\,\text{BIC} - .01\,\text{AGE} + .31\,\text{MULT} \quad (1f)$$

$$\ln Y = .69 + .24\,\text{FIREBRK} + .63\,\text{FUELBRK} - .82\,\text{BIC} + .05\,\text{AGE} + 2.71\,\text{MULT} \quad (1m)$$

$$\text{lN } Y = 1.13 - .15\,\text{FIREBRK} - .04\,\text{FUELBRK} + 1.04\,\text{BIC} + .04\,\text{AGE} + .98\,\text{MULT} \quad (1t)$$

where

ln Y = natural logarithm of area burned (ha);
FIREBRK = area of primary firebreak encountered (ha);
FUELBRK = area of primary fuelbreak encountered (ha);
BIC = Burning Index Classes

$$= \begin{cases} 0 \text{ if low fire danger,} \\ 1 \text{ if moderate fire danger,} \\ 2 \text{ if high fire danger,} \\ 3 \text{ if very high fire danger,} \\ 4 \text{ if extreme fire danger;} \end{cases}$$

AGE = time since last burn (yr);

$$\text{MULT} = \begin{cases} 1 \text{ if at least one other fire was burning concurrently,} \\ 0 \text{ if not.} \end{cases}$$

Standard errors

	FIRE-BRK	FUEL-BRK	BIC	AGE	MULT	R^2	F	sig	n
Front	.01	.09	.35	.01	.77	.40	6.44	.01	55
Mid	.10	.03	1.00	.05	.68	.69	5.91	.01	19
Trans	.12	.03	.48	.02	.35	.22	2.26	.07	45

The regression equations for secondary encounters in the Front, Mid-main, and Transition zones respectively were:

$$\ln Y = 2.33 + .01\,\text{FIREBRK} + .81\,\text{BIC} - .01\,\text{AGE} + .78\,\text{MULT} \quad (2f)$$

$$\ln Y = 2.78 + .09\,\text{FIREBRK} + .02\,\text{FUELBRK} + .65\,\text{BIC} - .02\,\text{AGE} + 1.00\,\text{MULT} \quad (2m)$$

$$\ln Y = 4.74 - .01\,\text{FIREBRK} + .07\,\text{FUELBRK} + .10\,\text{BIC} - .01\,\text{AGE} + 1.49\,\text{MULT} \quad (2t)$$

where

ln Y = natural logarithm of area burned (ha);
FIREBRK = area of secondary firebreak encountered;
FUELBRK = area of secondary fuelbreak encountered;

$$\text{BIC} = \text{Burning Index Classes} = \begin{cases} 0 \text{ if low fire danger,} \\ 1 \text{ if moderate fire danger,} \\ 2 \text{ if high fire danger,} \\ 3 \text{ if very high fire danger,} \\ 4 \text{ if extreme fire danger;} \end{cases}$$

AGE = time since last burn (yr)

$$\text{MULT} = \begin{cases} 1 \text{ if at least one other fire was burning concurrently,} \\ 0 \text{ if not.} \end{cases}$$

Standard errors

	FIRE-BRK	FUEL-BRK	BIC	AGE	MULT	R^2	F	sig	n
Front	.01	---	.27	.01	.77	.35	3.49	.02	31
Mid	.03	.03	.68	.03	1.05	.62	1.98	.22	12
Trans	.01	.03	.22	.01	47	.32	3.38	.01	42

In developing the regression equations, the independent variables retained were those which exhibited statistical significance (90% level of confidence) in at least one zone, and for which the sign on the partial regression coefficient was justifiable upon further scrutiny of the data. Further, as the objective of the analysis involved an evaluation of the impacts of breaks upon burned area, the firebreak and fuelbreak variables were retained, regardless of significance.

The R^2 values indicate the proportion of variation in the dependent variable explained by the regression equations. Their magnitudes, while not particularly large, are indicative of the general complexity of fire phenomena. The R^2 levels seem satisfactory in terms of the objective of this study and of the significant levels attained by the included set of independent variables. Further justification is suggested by the levels of tolerable error which fire behavior modellers accept in their applications (Albini 1976).

Break Performances in the Front Damage-Potential Zone

The regression equations for evaluating the performances of firebreaks and fuelbreaks in the Front zone are presented above. The outcome of primary encounters is summarized as equation 1f, that of secondary encounters as equation 2f. In general, the analysis showed that firebreaks and fuelbreaks constructed at unit boundaries were weakly associated with lower levels of area burned in this zone. The magnitude and sign of the partial regression coefficient for the FUELBRK term in equation 1f permit an evaluation of the change in area burned beyond encounter that might have been expected had additional fuelbreaks been encountered during the study period. For instance, if fuelbreak construction efforts had doubled the area of fuelbreak interception. there would most likely have been an associated 10 percent decrease in the observed level of area burned beyond a primary encounter, assuming all other factors were held constant. However, there was considerable variability in the relationship, as fire weather severity played an important role in determining the success or failure of the break segments tested. In fact, in the long run, two of every three times the range between a 25 percent decrease and an 8 percent increase over the base burned area might result, computed from a confidence interval extending to one standard error on either side of the most likely value.

Lateral or secondary encounters seemed to have no influence on the area burned within the unit of origin. This may reflect a tendency for fire managers to concede portions of watersheds which are unsafe or hazardous for direct fire attacks. Instead a strategy which calls for withdrawing to major control lines along the boundaries of a drainage basin may be implemented more often than in the past.

Break Performance in the Mid-Main Damage-Potential Zone

The regression equations for the break performances on primary and secondary encounters are summarized in equations 1m and 2m, respectively. The analysis showed firebreaks and fuelbreaks to be least successful in this zone, in that fires such as the Mill and Village fires (1975) overran considerable portions of completed break segments. In contrast to the Front zone, the Mid-main units are less accessible and traditionally have not received as high a priority for fire protection, despite an ever-increasing rate of fire ignitions during the study period. Despite their ability to contain most of these ignitions to the smaller size classes, fire managers face a small, but significant, number of fires which may escape, even in the presence of increased levels of fuelbreak construction.

Break Performances in the Transition Damage-Potential Zone

A negative association was shown between primary encounters and areas burned. In comparison to the Front zone, a doubling of fuelbreak interceptions would most likely be

associated with an eight percent reduction in the area burned. However, there is a smaller range in variability associated with this change, as the confidence interval of comparable width spans a range from 14 percent to 2 percent reductions in the area burned beyond primary encounters.

Break Performances in the Desert Damage-Potential Zone

There were too few encounters to establish a regression relationship for either type of encounter in this zone. While large fires have historically occurred in this zone, their occurrence is rare enough to likely justify a less costly type of fire management investment, such as the construction and maintenance of helicopter landing spots.

DISCUSSION

Firebreak and Fuelbreak Performances

The equations presented provide a measure of the associations which exist between past investments in preconstructed firebreaks and fuelbreaks and area burned on the Angeles National Forest during the study period. These equations suggest that fire managers have been aided by the presence of primary fuelbreaks in the Front and Transition zones, though not in all cases. On the other hand, primary encounters in the Mid-main zone and secondary encounters in all zones have not been associated with reductions in area burned. The equations for the secondary encounters suggest that increases in secondary breaks may not be associated with decreases in the area burned within the unit of origin. This finding suggests that under a management objective which calls for the minimization of areas burned by large wildfires, investments in secondary or lateral breaks have not necessarily paid off. On the other hand, a management objective which incorporates age-class manipulations via prescribed burning or other modified suppression programs will likely require a network of secondary or lateral breaks as part of the total fuelbreak system. This distinction suggests the incompatibility of the traditional "minimum burned area" objective with progressive fire management programs.

The magnitudes of the partial regression coefficients for the break terms which have negative signs give an indication of the magnitude of reductions in area burned which might be expected as break construction increases, all other factors held constant. These estimates are probably conservative in that many of the breaks encountered may not have been up to present day standards or may not have been utilized to full advantage. As with any innovation, a trial and error period of considerable duration may precede judicious application.

Planning for Future Management Alternatives

Since 1972 the Angeles National Forest has been engaged in an accelerated fuel management program, justified in part by fire gaming techniques. Experienced fire managers participated in these simulation games in preparing the environmental analysis reports for proposed fuel management projects. The estimates of fuelbreak productivity contained in this reports are generally more promising than those reported in this study. One reason for the discrepancy is that the fires simulated in these reports were gamed under "average worst" conditions of fire behavior, conventionally assumed to be the 95th percentile of daily burning index measurements over the period 1960-9. Such an analysis explicitly excludes consideration of those few fires which cause a disproportionate share of suppression costs and damages. In contrast, the fires examined in this study have burned under the full range of fire environments present in each zone during the period 1960-75. Inclusion of those fires which burned under the most extreme burning conditions would understandably lead to more conservative estimates of productivity. Further, the fire simulations for the environmental analysis reports compared the area burned with and without a fuelbreak system constructed and maintained to full standards, with adequate manning and technological support. These conditions enable the fire managers to make more optimistic projections than those presented in the foregoing analysis. This study to date points out that actual performance in the near future could be substantially less than predicted in the environmental analysis reports, due to the variability of fire-fuelbreak interactions and conditions which violate the assumptions under which the fire simulations were conducted. It would be prudent for fire management planners to inform their concerned publics of this possibility.

A mathematical program is currently being generated in which the projected reductions in the environmental analysis reports are assumed reasonable, even if misleading of expected performances in the near future. The output from this program will represent

represent a first approximation to a multi-year allocation scheme for construction and maintenance activities in each damage appraisal unit. An assessment will be made of the sensitivity of the program to reductions in the estimates of fuelbreak productivity, constraints on management resources, and changes occurring over time in the burnable area within a damage appraisal unit.

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CHAPARRAL GROWTH AND FUEL ASSESSMENT

IN SOUTHERN CALIFORNIA[1/]

Ronald H. Wakimoto[2/]

Abstract: Destructive wildfires occur nearly every year in southern California. To best allocate fire management resources a rapid, easy to use method of fuel inventory is needed. The basis for such a system is presented utilizing linear regression techniques. Individual plants are measured and their volumes approximated. Significant relationships between plant volume and biomass are presented. Such relationships are species specific.

Key words: fuel inventory, plant volume, fuelbreak, fuel buildup, biomass prediction equations, live woody fuel, linear regression analysis.

INTRODUCTION

The extreme wildland fire problem in southern California arises from a unique combination of climate, vegetation, and people. Destructive brush fires occur nearly every year in southern California, resulting in tremendous social and economic impact. As the years have passed since the inception of the fire exclusion policy by agencies such as the California Department of Forestry and the U.S. Forest Service, wildfires have become more intense and costly. The major factor accounting for such fires is the buildup of fuels in the form of plant growth and the lack of natural periodic fire (Dodge 1972).

To effectively control large wildfires in such wildland fuels, the land management agencies, such as the U.S. Forest Service, Bureau of Indian Affairs, Bureau of Land Management, and the California Department of Forestry have embarked on a program of fuel management which seeks to reduce wildfire damage through the reduction of vegetative fuels (Bentley and White 1961; Montague 1974; Weissenberger 1974). Montague 1974; Weissenberger 1974). Currently, the most important aspect of such management is the construction of fuelbreaks, which are wide strips or blocks of land on which natural vegetation has been partially or totally removed and replaced by vegetation of lower volume and hazard (Brown and Davis 1973). There exists approximately 2980 kilometers of maintained fuelbreaks in California (Weissenberger 1974).

Fuelbreak Construction

Fuelbreak construction techniques are varied depending on available funding, available equipment, topography, soil characteristics, and vegetation structure and density. Mechanical, chemical, and prescribed burning techniques are frequently used in combination to construct and maintain such breaks.

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Mechanical Techniques

Mechanical manipulation of chaparral is the primary technique used to construct fuelbreaks in southern California. Large crawler-type tractors are employed to clear the vegetation using a variety of additional implements (Roby and Green 1974, 1976; Green 1977). On small scale projects a dozer blade set approximately 30 cm above the ground is used to push over the plants. Special dozer blades, brush rakes or rock rakes, which allow the surface soil to pass through them, are also used (San Diego Co. Watershed Resources Advisory Commission 1973). Various brush cutters and large agricultural disc implements are employed where terrain and fuel type permit (Frank, et al., 1970). On larger projects navel surplus anchor chains, often weighing 45 kg per link, are pulled between two large crawler-type tractors to break the vegetation off at ground level (Dodge and Pierce 1962). Such chains have also been modified by adding steel bars running across the width of each link. These bars allow the chain to dig into the soil and uproot may plants (Watershed Resources Advisory Committee 1973). On steep terrain, such as sharp ridgetops, a large metal ball is attached to one end of the the chain instead of a tractor. The tractor at the other end of the chain moves along the ridgetop with the ball pulling downhill holding the chain against the slope to crush the intervening brush (Gilbert and Schmidt 1970).

All these techniques differ in their effectiveness in removing chaparral. Some methods remove only older plants which resist manipulation while leaving young, resilient plants unharmed. Other techniques alter species composition drastically because of differential resistance to the manipulation and differences in sprouting ability. Still other techniques increase seedling establishment by removing competition and scarifying hard seed coats for better germination. Little is known quantitatively about the rate of plant regrowth and fuel buildup after manipulation relative to fuelbreak maintenance and fire control effectiveness.

Chemical Techniques

Chemical herbicides, such as 2,4-D and 2,4,5-T and their mixtures, have been used extensively in the past two decades to control chaparral sprouts and seedlings on fuelbreaks originally cleared by fire or mechanical techniques. Effectiveness of control is limited by the season of application, method of application, plant growth stage, species susceptibility, and the size and crown volume of the plant at the time of application (Leonard and Harvey, 1956, 1965; Plumb and Bentley 1960; Plumb 1969). The latter variable is the least understood relative to effective herbicide application. Apparently large crown volume prevents stem flow of the herbicide and subsequent plant kill (Plumb 1971). In such cases the outer leaves are killed by the spray, but the plant is seldom affected unless herbicide application is repeated for two or three consecutive years (Leonard and Carlson 1957).

Prescribed Fire

Fire has not been used extensively to create fuelbreaks. It has been used primarily for type-conversions to change high site brushland into grazing land (Sampson and Burcham 1954). Much research has centered on this conversion process (Bentley 1967). Fire has been used to clear away mechanically manipulated fuels (Blandford 1962). The clearing effect of wildfire has been utilized to produce fuelbreaks in many areas.

Fire as a management tool may have its greatest value in manipulation of chaparral between fuelbreaks. Regardless of the fuel reduction on fuelbreaks no reduction of fire intensity or fire damage can be expected in the intervening areas if they are burned by wildfire (Davis 1965). The greater the fuel buildup in these blocks of vegetation, the less effective the fuelbreak will be under any set of weather conditions (Davis 1965). In order to use fire effectively as a management tool, the chaparral must be evaluated as a fire fuel, and then related to fire behavior (Countryman 1969).

The weight of available fuel is an important determinant of fire behavior. It depends on the quantity and quality of growth of individuals and the density of the stand. The heat of the fire front must drive off moisture in the preceding fuel before it can be consumed. The finer the particle the more easily it is heated and consumed. In green vegetation the finer fuels also display the greatest variation in moisture content which also limits the amount of available fuel (Dell and Philpot 1965). The amount of dead fuel in a stand is also a very important variable since such fuels respond to current climatic changes and may either augment or limit the fuel available to the fire (Schroeder and Buck 1970). High stand den-

sity leads to excessive side shading as the plant crowns grow to occupy the site. This causes mortality of lateral branches (Dodge 1972). Periodic drought accentuates this problem (Buck 1951). In addition, mortality of relatively short-lived shrub species increases this dead fuel load over time (Hanes 1971).

THE PROBLEM

A problem common to all land management agencies holding chaparral covered lands is the lack of a simple, accurate method of sampling brushland fuel in terms of both quantity and quality. Current methods involve plot clipping, weighing, and drying for each estimate. These techniques are so costly in terms of time and money that few actual samples have been taken in chaparral research. An alternative sampling method is needed. Only by inventorying the vegetation as a fire fuel can meaningful values of fire hazard be assigned and resource allocations evaluated.

STUDY SITE

A large fuel management demonstration site, selected by the Task Force on California's Wildland Fire Problem (Task Force on California's Wildland Fire Problem 1972), is the study site for the research presented in this paper. Christened the Chaparral Research, Environmental Analysis, and Management area or C.R.E.A.M. area, this site in San Diego County consists of approximately 51,400 hectares of chaparral vegetation composed primarily of chamise (*Adenostoma fasciculatum* H. & A.), red shanks (*Adenostoma sparsifolium* Torr.), Eastwood manzanita (*Arctostaphylos glandulosa* Eastw.), cupleaf ceanothus (*Ceanothus greggii* var *perplexans* (Trel.) Jep.), western mountain mahogany (*Cercocarpus betuloides* Nutt. ex T. G.), California buckwheat (*Eriogonum fasciculatum* Benth.), and scrub oak (*Quercus dumosa* Nutt.). The elevation of this area ranges from approximately 900 meters up to over 1,800 meters at the top of Laguna Mountain. It contains lands held in public ownership and/or administered by the U.S. Forest Service, Bureau of Land Management, Bureau of Indian Affairs, California Department of Parks and Recreation, and the California Department of Forestry.

METHODS

Plants utilized were harvested in the fall of 1974 and 1975. Plants of each species were selected to be representative of existing stands of chaparral. Plants on or adjacent to fuelbreaks subjected to excessive browsing or other mechanical damage were rejected. All plants up to 10 years of age represent open grown plants found on fuelbreaks or recently burned areas. Older plants were collected from unaltered stands which had recovered from past fires. Such plants are representative of growth after crown closure and competition for light and water.

Prior to actual harvest of each plant the following observations and measurements were made:

1. plant height (cm)
2. plant crown diameter (cm)
3. height at maximum diameter (cm)
4. plant type (seedling or sprout)
5. tally of basal stems by diameter classes

Height represents the average total plant height. Diameter represents the average of the maximum crown diameter and the crown diameter taken at a right angle to it. The variable height at maximum diameter is the height at which maximum diameter occurs. Plant type was determined by observing plant species and the presence or absence of a well developed root crown and/or standing dead stems left over from the last fire. The number and diameter of basal stems may give some indication of plant vigor prior to the last disturbance and account for an appreciable amount of plant biomass (Peek 1970; Brown 1976). All basal diameters were taken at ground level or immediately above the root crown. The four basal stem diameter classes were:

SPROUT1	0.0 - 0.5 cm
SPROUT2	0.6 - 1.0 cm
SPROUT3	1.1 - 2.5 cm
SPROUT4	> 2.5 cm

Actual harvesting consisted of cutting plants off at the ground level or immediately above the root crown. This material was

placed in labeled plastic bags for transport back to the laboratory. In certain cases exceptionally large plants were subsampled by cutting, and bagging a representative portion of the plant. This portion was immediately weighted in the field, as was the remainder of the plant. In this way the percentage of the total plant weight actually sampled and processed could be obtained and corrected for. For all plants, age was determined by growth-ring counts and fire history or fuel manipulation information.

In the laboratory each plant was calipered, clipped, and sorted into fuel diameter classes (table 1). Live and dead materials were distinguished visually and sorted. These materials were then dried to constant weight in a forced-air oven at 65°C.

Table 1--Fuel-type diameter classes.

CLASS	TYPE	DIAMETER RANGE
		cm
1	live	leaves
2	dead	leaves
3	live	0.0-0.5
4	dead	0.0-0.5
5	live	0.6-1.0
6	dead	0.6-1.0
7	live	1.1-2.5
8	dead	1.1-2.5
9	live	>2.5
10	dead	>2.5

Five additional independent variables were created using the plant measurements of height (Height), diameter (DIA), and height at maximum diameter (HTMAXD). These generated variables are presented in Table 2. COVER represents shrub canopy area computed as the area of a circle. It is essentially the vertical projection of the canopy edge down to the ground surface. PVOL1 represents the volume of a right cone utilizing the HTMAXD as the cone height with a base diameter equal to DIA. PVOL2 is a volume formed by the addition of PVOL1 to one-half the volume of a sphere with a radius equal to Height-HTMAXD. PVOL3 is the volume of a sphere with diameter equal to DIA. USFSVOL is a cubic shaped volume equal to DIA squared times Height. This variable approximates length x width x height volumes frequently used in fuelbreak regrowth inventory by the U.S. Forest Service. Lyons (1968), Bentley and others (1970), Peek (1970), and Burk and Dick-Peddie (1973) all have used volume-type measures to estimate vegetation biomass and production.

Least-squares regression techniques were employed to analyze the relationship of dependent variables (plant biomass) with the measured, tallied, or computed independent variables. A list of such variables follows:

Total Plant Weight (kg)

Total Live Weight (kg)

Weight of Fuels < 1.0 cm diameter (kg)

Weight of Fuels > 1.0 cm diameter (kg)

Total plant weight (WeightT) is the total oven-dry weight of a plant found by summing up all fuel classes. Total live weight (WeightG) is the total oven-dry weight found by summing up all odd numbered fuel classes. The weight of fuels less than or equal to 1 cm in diameter (Light) is the sum of fuel classes 1 through 6. These light fuels are generally consumed by wildfires of any intensity. The weight of fuels greater than 1 cm in diameter (Heavy) is the sum of fuel classes 7 through 10. Heavy fuels of this size are often not consumed in fast moving chaparral fires.

Table 2--Generated independent variables.

VARIABLE	COMPONENTS
COVER	COVER = PI x $(DIA/2)^2$
PVOL1	PVOL1 = 1/3 x PI $(DIA/2)^2$ x HTMAXD
PVOL2	PVOL2 = PVOL1 + (4/3 x PI x $(HEIGHT - HTMAXD)^3$) x 0.5
PVOL3	PVOL3 = 4/3 x PI x $(DIA/2)^3$
USFSVOL	USFSVOL = DIA^2 x HEIGHT

Variables were first run one on one. Then each dependent variable was run against an appropriate set of independent variables in stepwise fashion.

RESULTS

Simple Linear Regression

In general linear plant measurements did not account for a significant amount of variation in plant biomass. The poorest individual measurement was height at maximum diameter. Diameter was the best predictive linear measurement in terms of the regression coefficient. Height, while accounting for biomass at early ages, failed to account for the stem increment growth once maximum height had been reached.

Cover or crown area offers great promise as a single, easily measured variable. Depending on the plant species involved it alone accounted for from 30 to 95 percent of the total biomass variation.

The generated volumes were clearly better than linear measurements for estimating all dependent variables examined. Each plant species can be associated with a generated volume shape that best accounts for its total above ground biomass:

Chamise	PVOL2 (R^2 = .90)
Red shanks	PVOL2 (R^2 = .98)
Eastwood manzanita	PVOL3 (R^2 = .90)
Cupleaf ceanothus	USFSVOL (R^2 = .66)
Mt. mahogany	PVOL1 (R^2 = .85)
Calif. buckwheat	PVOL1 (R^2 = .94)
Scrub oak	USFSVOL (R^2 = .80)

Stepwise Linear Regression

The stepwise regression analysis combined the plant volumes and basal sprout tallies. Linear measurements were not used in this analysis to maintain independence among the "independent" variables. The results can be seen in table 3a and table 3b. All predictive equations accounted for statistically significant (0.05 level) amounts of variation in the dependent variables.

Table 3a--Predictive equations resulting from stepwise regression.

SHRUB SPECIES[1/]	PREDICTIVE EQUATION Y = WEIGHTT (kg)	R^2[2/]	SEE
ADFA	Y= .061+4.728 PVOL2 -.794 SPROUT4	.9469	.2139
ADSP	Y= .192+10.216 PVOL1 -1.794 SPROUT4	.9985	.1069
ARGL3	Y= .543+1.863 PVOL3 +.775 SPROUT4	.9379	.4336
CEGRV	Y= -.243+7.767 PVOL1 +.230 SPROUT3 + .130 SPROUT2	.8202	.6372
CEMO2	Y= -.967+13.130 PVOL1	.8507	.7413
ERFA2	Y= -.186+14.236 PVOL1	.9426	.2552
QUDU	Y= -.596+2.338 PVOL2 +.340 SPROUT3	.8244	1.5977
	Y = WEIGHTG (kg)		
ADFA	Y= .130+3.552 PVOL2 -.935 SPROUT4	.9112	.1994
ADSP	Y= .178+9.785 PVOL1 -1.742 SPROUT4	.9986	.0986
ARGL3	Y= .520+1.746 PVOL3 +.704 SPROUT4	.9324	.4189
CEGRV	Y= -.218+7.363 PVOL1 +.220 SPROUT3 + .134 SPROUT2	.8052	.6400
CEMO2	Y= -.749+11.607 PVOL1	.8825	.5723
ERFA2	Y= .194+11.508 PVOL1	.9236	.2399
QUDU	Y= -1.071+1.830 PVOL2 +.394 SPROUT3	.9096	1.0929

1/ All plant name symbols taken from Soil Conservation Service (1971).

2/ All R^2's presented are adjusted for the number of independent variables in the eouation and sample size.

Table 3b--Predictive equations resulting from stepwise regression.

SHRUB SPECIES[1/]	PREDICTIVE EQUATION Y = LIGHT (kg)	R^2[2/]	SEE
ADFA	Y= .154+3.073 PVOL2 -.742 SPROUT4	.8301	.2511
ADSP	Y= -.216+.730 USFSVOL -.621 SPROUT4 + .089 SPROUT2	.9921	.1165
ARGL3	Y= .365+2.284 PVOL3	.8651	.4480
CEGRV	Y= -.153+2.25 PVOL1 +.168 SPROUT3 + .199 SPROUT2 +.635 SPROUT4	.8829	.3597
CEMO2	Y= -.266+7.831 PVOL1	.8674	.4132
ERFA2	Y= -.152+10.508 PVOL1 +.052 SPROUT3	.9743	.1515
QUDU	Y= -.484+1.781 PVOL3 +.261 SPROUT3	.8447	1.1393
	Y = HEAVY		
ADFA	Y= -.056+.270 PVOL2 +.071 SPROUT3	.8039	.1759
ADSP	Y= -.190+1.882 PVOL2 +.162 SPROUT4	.9958	.0976
ARGL3	Y= -.744+.255 PVOL3 +.382 SPROUT4 + .028 SPROUT3	.9698	.0954
CEGRV	Y= -.113+3.583 PVOL1	.7918	.2849
CEMO2	Y= -.701+5.299 PVOL1	.8081	.3467
ERFA2	Y= -.108+1.710 PVOL1	.8536	.0509
QUDU	Y= .222+.452 USFSVOL -.109 SPROUT2	.8441	.4143

1/ All plant name symbols taken from Soil Conservation Service (1971).

2/ All R^2's presented are adjusted for the number of independent variables in the equation and sample size.

Total Weight and Total Green Weight

Chamise and red shanks have negative coefficients for SPROUT4 in their predictive equations. This is puzzling since it implies that a plant with volume X and no large basal sprouts would have greater biomass than one of volume X and a number of basal sprouts greater than 2.5 cm in diameter. Perhaps such species become decadent by the time basal sprouts reach this size and the individual's biomass is actually decreasing through the loss of smaller basal sprouts, twigs, and foliage.

Light and Heavy Fuels

In relation to the biomass of fuels less than 1.0 cm in diameter, chamise and red shanks again display a negative relationship with large basal sprouts. This adds plausibility to the previous explanation of these negative coefficients. The greater the number of large basal sprouts, the less light fuel per plant. For the biomass of fuels greater than 1 cm in diameter, except for scrub oak, the predictive equations are self-explanatory. The more large basal sprouts present, the greater the heavy fuel biomass. As for scrub oak, SPROUT2 has a negative coefficient. No clear explanation for this is evident.

SUMMARY

The predictive equations presented offer a method for fuel loading assessment. Both total fuel loading and available fuel loading can be estimated. These equations are species specific and may be area specific. The methods used to develop such predictive equations can and should be applied to many other chaparral areas.

The equations presented will allow rapid inventory of vegetation regrowth following fuel manipulation or wildfire. Additionally, net above ground biomass production can be estimated through repeated measurement of individuals over time.

This research was supported in part by the University of California, Water Resources Center, Project UCAL-WRC-W-490.

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DECOMPOSITION IN CHAPARRAL[1]

Lin Yeilding[2]

Decomposition rates were measured by a polyester bag technique. Rates in percent weight loss are compared for three species, seven fuel classes (foliar and woody stem diameter classes), and three positions (buried, surface and aerial). Differences in rates were shown for species, between foliar and woody fuel classes and position. Analysis of initial nutrient content showed differences between fuel classes but not species. The variables then that are responsible for decomposition rates are probably multiple, including nutrients as well as environmental factors.

Key words: chaparral, decomposition, nutrients, fire, fuel manipulation

INTRODUCTION

Despite our best fire prevention and suppression efforts, California chaparral wildfires will continue to occur when the combinations of dry weather, low fuel moisture and high fuel load unite.

Wildfires do great social damage, but not necessarily ecological damage. Fires are a necessary and healthy part of a chaparral ecosystem (Hanes 1971). As long as people continue to settle in these areas, wildfires as a social problem will continue to exist.

A manager dealing with this problem finds himself/herself constrained by social, economic, ecological and managerial systems. Socio-economic constraints are clearly set by public opinion and costs. On the other hand, we know little about the ecology of chaparral and how it is affected by management. How can managers deal with the problem with this information void in the total system? Thus, we need to have a better understanding of the biological system; how it interacts with weather and other abiotic factors to produce fires and how to manage it, and do so within the socio-economic restrictions.

Major missing links in our understanding of the total chaparral ecosystem are decomposition and nutrient cycles. These processes have been well studied in other vegetation types by Bocock et al. (1961), Gilbert and Bocock (1960), Witkamp (1966), Broadfoot and Pierre (1939), Jenny et al. (1949), and Gosz et al. (1973). However, in chaparral our information is limited. Kittredge (1955) studied biomass dynamics of chaparral types at San Dimas Experimental Forest and calculated decomposition rates as the difference between annual accumulation and total accumulation of litter. He did not measure decomposition directly, however. Much research work has been devoted to decomposition of woody plant materials (Allison and Klein 1961; Agee et al. 1973) but not to chaparral woody material specifically.

Nutrient additions by fire and the nutrient content in chaparral soils and differences in dynamics of unburned and

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[1]Presented at the Symposium on Environmental Consequences of Fire and Fuel Management in Mediterranean Ecosystems, Palo Alto, Calif. Aug. 1-5, 1977.

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burned areas have been studied by Christensen and Muller (1975). Specht (1969) compared nutrient uptake of chaparral species with vegetation brush types in different parts of the world. Zinke (1969) studied nitrogen budgets of chaparral with lysimeters. Tracing nutrient changes with decomposition has only been studied in other vegetation types (Burges 1956; and Gosz et al. 1973).

Thus, a project was funded by the Water Resources Center and the Agricultural Experiment Station of the University of California to conduct a comprehensive analysis of the fuel dynamics of major chaparral species. The study area chosen for the project was the C.R.E.A.M. demonstration area in San Diego County, California, which is representative of the chamise-chaparral type of southern California and also site of the disastrous Laguna Fire of 1970.

The objective of my part of the project was to determine decomposition rates and to monitor nutrient and gross energy changes with decomposition.

METHODS

A modification of the standard nylon bag technique was used, where the plant material to be decomposed is contained in nylon bags inert to the decomposition process.

The bags used were made of a one hundred percent polyester material since polyester is inert like nylon but is less susceptible to deterioration by ultra violet sunlight. The mesh size of the bags was fine, similar to a 60 mesh screen. A discussion of the importance of mesh size in bag sutudies can be found in the literature (Suffling and Smith 1970; Gilbert and Bocock 1960). The small mesh size was chosen in order to minimize spillage, but still allow penetration by moisture, air and microorganisms. The bags were about 15 cm square, made by doubling over a strip of fabric and sewing the two sides.

The substrate to be decomposed was plant material of different chaparral species and different diameter fuel classes. Several plants were selected randomly in the field for each species. Each plant was then separated into the different fuel classes and then all the plants were combined within each fuel class for each species. The species studied were: Quercus dumosa (scrub oak), Adenostoma fasciculatum (chamise) and Ceanothus greggii. The following fuel classes, similar to Countryman's (1970) fuel classes were studied for each of the species: foliage, live and dead stems less than .5 cm in diameter, live and dead stems .6 to 1.0 cm in diameter and live and dead stems 1.1 to 2.5 cm in diameter.

Plant material was placed in bags individually and the exact weights determined. The open ends of the bags were sewn shut.

In addition to the species and fuel classes three positions were studied: buried, surface and aerial. The buried position simulated both natural burial of plant material by litter fall, but also mechanical burial by fuel manipulations, such as brush raking or chaining. The aerial position simulated standing aerial fuels in the shrub canopy.

Sites were established for each species, representative of typical stands where individual species were abundant. The bags were arranged randomly in plots for each collection period. Buried bags were placed 6 cm below the soil surface. Surface bags were secured on the soil surface. The aerial bags were tied in the shrub canopy at least 20 cm above the soil surface.

All possible combinations of species, fuel class and position were used and replicated five times, forming a complete randomized design.

A set of bags were collected after six months. The bags were brought to the laboratory and dried at 65°C and weighed. Subsamples of each type of species-fuel class combination had been taken at the time the bags were originally prepared to determine the moisture and ash content before decomposition.

After weighing, each bag was opened and the plant material was removed and ground to pass a 30 mesh screen. Each empty bag was reweighed, and this weight subtracted from the total weight.

Final disappearance rates were expressed in percent dry, ash-free weight loss.

Each ground sample, along with subsamples from the undecomposed samples were then analyzed for nutrient content. Nitrogen was determined by the Kjeldahl method (Chapman and Pratt 1961). Phosphorus was wet digested with a mixture of perchloric and nitric acids, and analyzed by colorimetry with a DU spectrophotometer (Johnson and Ulrich 1951

and Chapman and Pratt 1961). Calcium was wet digested and analyzed with an atomic absorption spectrophotometer (Varian Techtron 1972). Energy was determined by bomb calorimetry (Parr Instrument Co. 1975). The nutrients were expressed in percent and energy in calories.

RESULTS

The appearance of the bags when collected from the field showed different types of biological activity. There were visible differences in the three positions studied. Increasing evidence of biological degradation was observed throughout the time of the study. Different types of fungal growths and animal invertebrate activity were noted. Some general observations will be noted here.

Buried bags showed the most biological activity. They were impregnated with fungal growth, and the substrate was dark and humic in appearance after six months. Surface bags had fungal growths and dark coloration but to a lesser degree than the buried bags. The aerial bags, on the other hand, showed little evidence of fungal attack even after two years. Weathering was evident, however, in the aerial bags. The foliar samples were brown and broken into smaller pieces. The woody samples generally had the bark stripped from the stem and the stems were cracked and brittle.

The species appearing to show the most evidence of biological activity in decreasing order were C. greggii and A. fasciculatum. Q. dumosa appeared to rapidly decompose in the buried position but was resistant in the aerial position. Successive collections showed increasing signs of biological activity and degradation. In the surface and aerial positions the wood was almost powder by the fourth collection, and heavily infested with fungus.

The bags showed some evidence of larger invertebrate presence. Earthworm trails going through the bags and holes from the mouth parts of insects were observed. Termite activity was also noted in some of the woody samples in the aerial position. Many bags had been molested in some way by small mammals, without disturbing the material inside.

Mean decomposition rates and their descriptive statistics for the three species are shown in tables 1 through 3.

Table 1--Mean decomposition rates and statistics in percent weight loss for Q. dumosa by fuel class and position.

Fuel Class	Buried			Surface			Aerial		
	MEAN	STD.DEV.	N	MEAN	STO.DEV.	N	MEAN	STD.OEV.	N
Foliage									
6 mos.	30.78	2.87	5	19.70	3.57	5	11.70	2.60	5
12 mos.	43.17	4.94	5	23.72	4.20	2	17.41	.83	3
18 mos.	46.58	1.04	4	21.12	.29	2	15.46	2.04	5
Live LT .5									
6 mos	9.29	1.16	5	5.06	1.30	5	2.22	1.48	5
12 mos.	17.66	2.21	5	8.67	1.46	3	7.41	1.05	4
18 mos.	21.34	3.71	5	8.36	.97	2	5.78	2.48	5
24 mos.	24.85	2.08	4	0.	0.	0	11.41	3.72	4
Oead LT .5									
6 mos.	9.21	.63	4	4.58	.44	5	2.69	.97	5
12 mos.	25.22	.09	2	9.20	1.76	5	9.76	.89	4
18 mos.	22.92	2.18	4	22.58	0.	1	6.31	.54	3
24 mos.	31.52	5.28	3	0.	0.	0	9.45	5.20	2
Live .6-1.0									
12 mos.	12.92	3.32	3	5.24	1.04	4	4.19	2.38	5
24 mos.	27.35	4.47	3	4.72	3.05	3	6.37	1.95	5
Oead .6-1.0									
12 mos.	12.40	.67	4	5.21	1.73	5	8.04	1.93	5
24 mos.	34.70	.6.26	3	6.63	0.	1	7.47	1.96	4
Live 1.1-2.5									
12 mos.	14.54	4.38	4	6.2	1.87	3	5.31	.53	4
24 mos.	26.23	3.05	5	0.	0.	0	4.63	1.28	5
Dead 1.1-2.5									
12 mos.	14.14	3.04	5	5.16	1.85	5	8.38	5.51	5
24 mos.	21.32	4.74	4	9.63	0.	1	6.78	2.96	4

Table 2--Mean decomposition rates and statistics in percent weight loss for A. fasciculatum by fuel class and position.

Fuel Class	Buried			Surface			Aerial		
	MEAN	STO.OEV.	N	MEAN	STO.OEV.	N	MEAN	STO.OEV.	N
Foliage									
6 mos.	28.18	1.37	4	11.99	1.92	3	4.58	2.62	5
12 mos.	37.38	2.07	4	11.40	2.24	2	4.38	1.63	5
18 mos.	48.21	3.59	5	15.08	1.56	5	9.90	5.89	5
Live LT .5									
6 mos.	13.66	1.35	5	7.03	1.62	5	4.57	1.06	3
12 mos.	11.46	6.98	5	0.	0.	0	3.56	5.04	5
18 mos.	17.54	9.14	5	6.89	7.01	2	5.73	1.12	5
24 mos.	26.94	3.16	3	9.95	3.14	5	10.05	1.64	5
Oead LT .5									
6 mos.	8.22	5.47	5	-1.60	1.36	5	-2.48	1.11	5
12 mos.	16.92	7.35	3	0.	0.	0	-1.94	.23	5
18 mos.	19.88	6.22	5	17.10	18.84	3	13.73	4.56	5
24 mos.	27.01	8.00	4	0.	0.	0	-2.33	9.62	2
Live .6-1.0									
12 mos.	9.43	1.07	4	-1.87	1.29	5	2.95	2.16	5
24 mos.	19.78	1.90	2	7.44	2.19	3	3.60	2.42	3
Oead .6-1.0									
12 mos.	10.42	1.98	4	4.52	1.28	4	2.70	.89	5
24 mos.	23.74	13.16	2	7.75	6.53	3	5.36	1.15	2
Live 1.1-2.5									
12 mos.	6.05	2.92	4	1.65	1.77	5	2.49	2.04	5
24 mos.	15.40	8.07	2	-.84	.76	2	2.48	2.21	4
Oead 1.1-2.5									
12 mos.	4.12	2.76	5	2.13	1.57	5	2.67	5.02	5
24 mos.	17.71	0.	1	6.80	0.	1	2.21	1.65	5

Table 3--Mean decomposition rates and statistics in percent weight loss for C. greggii by fuel class and position.

Fuel Class	Buried			Surface			Aerial		
	MEAN	STO.OEV.	N	MEAN	STO.DEV.	N	MEAN	STO.OEV.	N
Foliage									
6 mos.	34.67	1.35	5	5.93	2.61	5	1.40	.82	5
12 mos.	39.93	1.01	5	12.40	3.04	5	5.15	3.05	5
18 mos.	49.99	8.60	4	12.86	5.99	5	6.47	3.68	5
Live LT .5									
6 mos.	12.15	1.48	5	4.99	1.31	5	3.89	.58	5
12 mos.	18.98	.98	4	7.39	3.26	5	5.76	2.49	4
18 mos.	21.43	3.59	5	5.42	2.06	4	11.08	4.53	5
24 mos.	29.79	9.75	4	8.42	3.13	3	14.41	2.70	4
Oead LT .5									
6 mos.	14.09	1.27	5	5.03	1.37	5	3.62	.12	5
12 mos.	18.77	7.14	5	5.93	4.83	5	5.52	1.14	5
18 mos.	22.14	10.16	5	8.00	2.27	4	8.69	1.91	5
24 mos.	32.77	8.79	5	10.45	1.26	4	8.94	5.78	4
Live .6-1.0									
12 mos.	11.22	2.10	5	6.18	2.17	5	4.03	1.01	5
24 mos.	24.68	9.37	4	1.32	5.04	2	5.09	1.35	4
Oead .6-1.0									
12 mos.	15.43	4.57	5	5.91	.74	4	4.68	1.01	5
24 mos.	17.15	5.03	5	1.94	0.	1	5.03	.88	4
Live 1.1-2.5									
12 mos.	9.39	2.46	5	6.51	2.99	5	4.99	3.46	5
24 mos.	11.17	0.	1	0.	0.	0	3.72	1.68	4
Oead 1.1-2.5									
12 mos.	7.23	2.35	4	2.68	.65	3	3.29	1.02	5
24 mos.	17.48	6.05	4	0.	0.	0	2.78	1.25	5

Figure 1 shows means plotted against time for Q. dumosa. In general, the foliar samples decomposed faster than the woody samples for all positions. Differences in rates of woody material are more diffcult to distinguish. In the buried position live tissue seems to decompose less readily than dead. In the surface and aerial positions the finer fuels (less than .5 cm) decompose slightly faster than the heavier fuels. In general, over all fuel classes decomposition decreases from buried to aerial positions.

A. fasciculatum rates are shown in figure 2. Foliage again is the fastest decomposer although there is less separation from the woody materials in the surface and aerial positions. No differences between live and dead woody fuels for any position are evident. On the other hand, the fine fuels appear to decompose more rapidly than the .6 to 1.0 cm. fuels which decompose faster than the heaviest fuels, for all positions. In the surface and aerial positions for chamise, negative decomposition or weight gain was recorded. This may be due to heterotrophic introduction of biomass into the bag.

Results for C. greggii are graphed in figure 3. Foliage is the fastest decomposer for the buried and surface position, but drops below some of the woody materials in the aerial position. In the buried and surface positions the woody fine materials seem to decompose faster than the heavier fuels in descending order as with A. fasciculatum. In addition, the dead fuels decompose slightly faster than the live fuels. In the aerial position, however, the live and dead fine fuels decompose faster than the foliar material. The .6 to 1.0 cm. class decomposes faster than the heavier fuels.

In comparing the three species it appears that C. greggii is the fastest decomposer, with A. fasciculatum only slightly slower over all. Q. dumosa has the slowest overall rates.

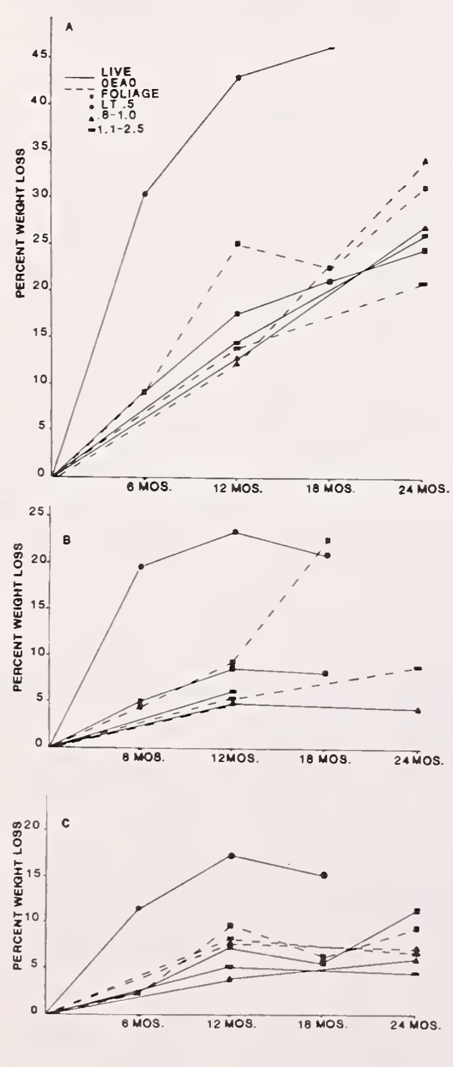


Figure 1--Mean decomposition rates and statistics in percent weight loss vs. time in months for Q. dumosa for each fuel class: (A) buried position, (B) surface position, (C) aerial position.

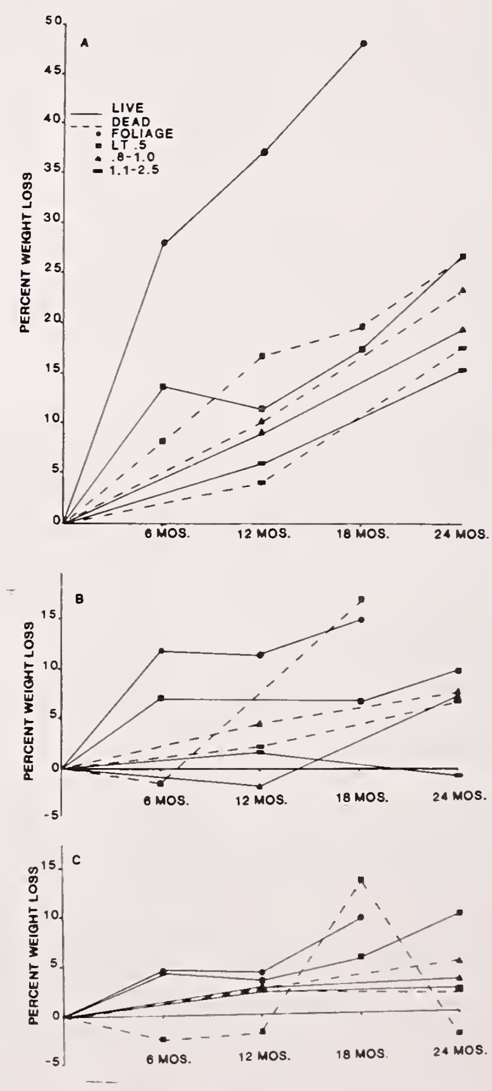
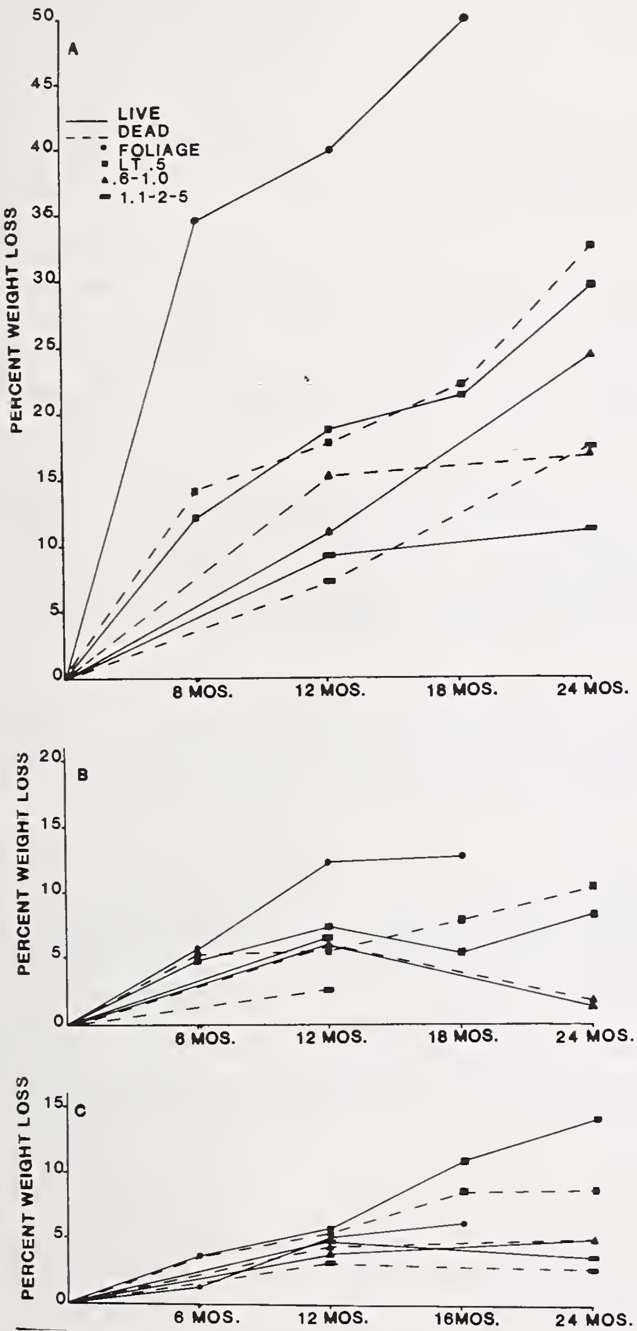


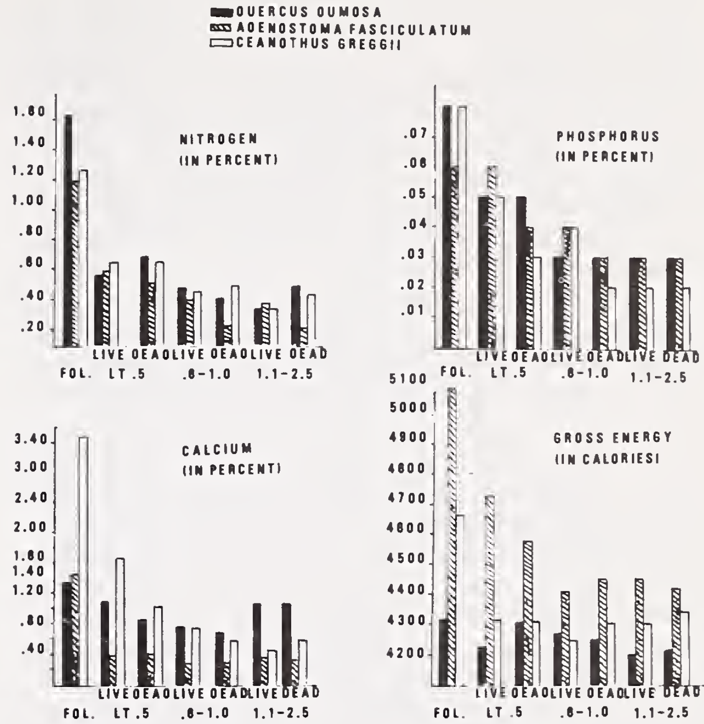
Figure 2--Mean decomposition rates in percent weight loss vs. time in months for A. fasciculatum for each fuel class: (A) buried position, (B) surface position, (C) aerial

Figure 3--Mean decomposition rates in percent weight loss vs. time in months for C. greggii for each fuel class: (A) buried position, (B) surface position, (C) aerial position.



Initial nutrient and gross energy content are shown in a histogram in figure 4, for each species and fuel class. Nutrient content tends to be a function of both species and fuel class, with no one species higher than any other for all fuel classes. Comparing fuel classes, however, foliage is higher for all nutrients, followed by the fine woody fuel classes, then the heaviest fuel classes. This was true for all species studied. In the case of gross energy, A. fasciculatum is higher overall than the other two species.

Figure 4--Mean initial nutrient content by species and fuel class.



DISCUSSION

Differences in position of surface and buried decomposing litter have been observed by Peevy and Norman (1948), who proposed that differences in the populations of microorganisms was the cause. Berg (1975) hypothesized that wind and sunlight desiccate exposed litter and thus reduced the decomposition rates he observed.

Differences in decomposition rates between species have been found in numerous similar studies of other species. Hayes (1965) showed different rates for different species in coniferous forest plantations. Gilbert and Bocock (1960) have shown differences in oak and ash leaf litter. Witkamp (1966) found differences in species decomposition at Oak Ridge, Tennessee. On the other hand, Weigert and Murdock (1972) have reported no significant differences in studies on old fields in Michigan. Agee et al. (1973) found no difference in decomposition rates of branch and twig components of eucalyptus litter. Even though different results have been reported in other vegetation types, based on results from this study, there are differences in decomposition rates demonstratable between species for chaparral. In addition, the rates observed seem to be closely tied to fuel class as well, especially between leaf and woody tissues.

Several possible explanations for this can be found in the literature. For example, Burges (1968) has discussed differences in sequences of fungal attack of decomposing litter. Witcamp (1966) compared microbial counts of different species of leaf litter and found them to be significantly different and also highly correlated with the different decomposition rates observed. Burges (1968) has shown different sequences of organisms associated with branch and cone litter as opposed to leaf material. Thus, it seems differences between foliar and woody classes and between species are closely tied with the type of microbial populations that attack the litter. Other explanations of differences in species decomposition could be due to the site and the accompanying abiotic factors, such as moisture, elevation, soil type and exposure. Site differences due to soil type have been discussed by Bocock and Gilbert (1957), and Bocock et al. (1961). In their sutdies of oak, ash and birch leaf decomposition, they hypothesized that differences between different species, and differences between the same species on different sites, were due to differences in heterotrophic activity and soil type. Bleak (1970) has discussed different moisture and temperature regimes and their effect on decomposition. Witkamp (1963) hypothesized that higher decomposition rates of some species were due to higher moisture content.

Nutrient content is also proposed to be an important influence in the decomposition process. Carbon to nutrient ratios are known to be an important driving variable in decomposition. The balance between the carbon substrate and the nutrients required by decomposing organisms will greatly affect the decomposition rate (Waksman and Tenney 1927). On the other hand, positive correlations between nutrient content and decomposition rate can not always be found (Bocock 1963). Results from this study seem to show that intitial nutrient content is not the only variable that explains the differences in decomposition rates observed. Initial nutrient content could explain the differences observed between fuel classes, however.

CONCLUSIONS

Preliminary results from this study indicate that decomposition rates vary according to position, species and fuel class, with the most obvious differences between positions and fuel classes. The explanation for these observed rates is not clear. Possible causes include different microorganisms attacking the different substrates, which is in turn determined by a complex interaction of nutrient and abiotic factors.

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POSTFIRE VEGETATIONAL RECOVERY, PRODUCTIVITY, AND HERBIVORE UTILIZATION OF A CHAPARRAL-DESERT ECOTONE[1]

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and

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Abstract: A canyon and ridge were sampled the year following a July fire in San Diego Co., California. All animal survived to actively use the burn. Of the 20 perennials sampled, 10 were chaparral and 10 were desert species. Resprouting occurred immediately and more commonly in the canyon than on the ridge. Recovery was high in chaparral shrubs and desert-wash plants, but low among cacti. Canyon plant productivity was greater than that on the ridge, with the greatest increases occurring in spring. Herbaceous plants contributed 64 to 76% of the year's productivity. Only 6 to 8 species were browsed by herbivores which consumed 4 to 8% of the available plants.
Key words: Postfire, recovery, productivity, herbivore utilization.

During July, 1975, the San Ysidro Fire burned over 4000 ha of montane chaparral and Colorado Desert scrub vegetation, including portions of Anza-Borrego Desert State Park, San Diego Co., California.

Because of a concern that this fire destroyed wildlife habitat, particularly that of the endangered desert bighorn sheep, and that little is known about fire and chaparral-desert ecotones, a one-year postburn study was conducted in the Penna Springs/Hellhole Canyon area at about 900 m elevation.[3]

[1] Presented at the Symposium on Environmental Consequences of Fire and Fuel Management in Mediterranean Ecosystems, Palo Alto, Calif. Aug. 1-5, 1977.

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[3] This study was conducted with the permission and cooperation of Anza-Borrego Desert State Park. We acknowledge the help of Bud Getty, James Locke, Sheena Tratz, Larry Pattin, William Tratz, Wallace Tratz, Sr., Westley Kansonet, Fred Jee, Craig Petersen, Rusty Vogl, and Barry Prigge.

METHODS

Canyon and ridge sites were established to sample the vegetational recovery and herbivore utilization. This was done by establishing 80 permanent quadrats at each of the two sites. Twenty of these circular quadrats (each 1/40 acre in size) were samples in the canyon and 20 on the ridge at the ends of each of the first four seasons following the fire. All individuals of each species present in each quadrat were counted. The resprouts of each perennial species were clipped at ground level and oven-dried at 85°C for 48 hrs. The length of each sprout was measured, and browsing by wildlife was recorded.

The herbaceous plant productivity was determined by clipping at ground level all herbaceous plants in 20 quadrats (each 1 m^2) in the canyon and 20 on the ridge. This was done in February, just after the peak of annual plant growth, and the clipped plants were oven-dried as above.

Percent cover of the perennial plants was obtained from 20 line-intercepts (each 30m long) in the canyon, 20 on the ridge, and 20 on an adjacent unburned area taken 1 yr after the fire. Unburned shrub densities were obtained with 20 circular quadrats, each 1/40 acre in size. Details of the methods are presented by Tratz (1977). Nomenclature of plant species follows Munz (1959).

POSTFIRE ANIMAL MORTALITY

A total of 90 man-hours were spent during daylight hours between 16 Aug. and 4 Sept., 1975 searching for fire-killed animals. Particular attention was paid to unburned coverts, large rock piles, dens, and caves where animals might have been killed but not consumed. Visibility was excellent because much of the vegetation was consumed to ground level. No dead animals were found during the search, including no fresh bones, fur, feathers, horns, or skins, with the exception of an unburned Hereford cow that apparently died after breaking her leg trying to escape the fire. Concentrations of scavengers were not observed, perhaps indicative of the absence of fire mortality. Unusual numbers of displaced animals were not found in the adjacent unburned vegetation.

But a number of living animals were observed on the fresh burn, and all appeared to be healthy and uninjured despite extremely hot postfire weather. Common sightings were made of lizards (3 species), ground squirrels (2 species), song birds, and coyote tracks and scats. Two desert bighorn sheep, a mule deer with a large fawn, 8 cottontail rabbits, and 1 vole were observed on the burn. Numerous sheep and deer tracks, and fresh browsing were also observed. Three coveys of mountain quail, 2 coveys of Gambel's quail, 2 burrowing owls, 1 red-tailed hawk, 1 sparrow hawk, 1 loggerhead shrike, 8 scrub jays, and 3 hummingbirds were counted in addition to the small song birds. Several snake tracks were observed in the ash, but only 1 king snake was seen. Ants were particularly active after the burn.

Although this desert-chaparral edge supported a variety of animals, was part of a wildlife refuge, including a refuge for desert bighorn sheep, and the fire was often fast-moving and hot, evidence of wild-animal mortality was not found.

VEGETATIONAL RECOVERY

Resprouting of burned perennial plants commenced almost immediately after the fire in the canyon, probably because of ground water, but was delayed on the ridge until a series of September thundershowers brought moisture. Resprouting plants in the canyon increased from 0 at the time of the fire to 377 plants/ha after 2 months, 1,662/ha after 4 months, to 1,518/ha after 7 months, and finally to 1,765 plants/ha after 10 months. The decline in numbers from 4 to 7 months is considered to be a sample variation resulting from the heterogeneous nature of the ecotone vegetation. On the ridge, there were only 10 resprouting plants/ha after 2 months, 422/ha after 4 months, 552/ha after 7 months, and 625 plants/ha after 10 months. Both sites had their greatest recovery from 2 to 4 months after the fire, with 66% (ridge) to 73% (canyon) of the year's total returned by then. By the end of the year, the canyon contained more than double the number of recovered perennials than the ridge, even though up to 1 m of canyon soil was removed in places by the September flash floods.

Postfire recovery responses varied with the season, site, and the 20 species of resprouting perennials sampled. *Eriodictyon trichocalyx*, *Quercus dumosa*, *Rhus ovata*, and *Acacia greggii* had the highest densities in the canyon, and *Encelia virginensis*, *Rhus ovata*, and *Quercus dumosa* were most common on the ridge. In the canyon, 82% of the recovering plants were primarily chaparral components, and 18% were more characteristic of desert areas. On the ridge, 40% were chaparral representatives, and 60% were desert types. Of the 20 perennial species sampled, 10 were chaparral and 10 were desert species. The surprising thing was that *Acacia greggii*, *Chilopsis linearis*, *Hymenoclea salsola*, *Encelia virginensis*, *Prunus fasciculata*, *P. fremontii*, *Yucca schidigera*, *Opuntia basilaris*, *O. acanthocarpa*, and *Echinocereus engelmannii*, which occur primarily in the desert, recovered from the fire by resprouting just like typical chaparral shrubs. The multiple-stem or coppiced growth forms of such desert species as *Chilopsis linearis*, *Acacia greggii*, *Yucca schidigera*, and others were observed to be a response to fire, a relationship that had not previously been made because of the relative infrequent nature of fire or other similar disturbances on the desert and the paucity of ecotonal studies.

Specific species responses, by season and habitat location, are presented in Tratz (1977). Two noteworthy species are the ferns, *Cheilanthes covillei* and *Pellaea mucronata*, which resprouted from charred rhizomes shortly after the fire.

Since prefire studies were not made, precise data on the recovery of the various species could not be obtained. Estimates of recovery were made for the common species from field counts and observations. The poorest recovery in the canyon was displayed by *Opuntia acanthocarpa*, with only about 25% resprouting. Estimates of cacti should be fairly accurate, since it is unlikely that these stem succulents would be completely consumed by fire. More than 75% of *Prunus fremontii*, *Ribes quercetorum*, and *R. malvaceum*

were estimated to resprout. The common canyon species, whether they were typical chaparral shrubs or desert-wash phreatophytes, had between 90 and 100% recovery.

Echinocereus engelmannii had the poorest estimated recovery of 10% on the ridge. About 25% of Opuntia acanthocarpa and 50% of O. basilaris on the ridge were observed to survive. Cercocarpus betuloides plants had about 75% recovery, while Encelia virginensis had a somewhat better survival. Encelia commonly burned to ground level making it difficult to locate dead individuals. Yucca whipplei appeared to have about 75% recovery, while more than 90% of the Y. schidigera on the ridge resprouted. Many of the Y. whipplei individuals might have been dead before the fire, since these plants normally die after flowering, thereby exaggerating the fire mortality estimates. The common species on the ridge, such as Rhus ovata and Quercus dumosa, had an estimated 90 to 100% recovery. Overall mortality was about twice as high on the ridge as in the canyon, and was mainly produced by the poor survival of cacti and the reduction of Cercocarpus and Encelia numbers, possibly because the fire was hotter on the ridge.

By the end of the first year, about 10% of the canyon and 5% of the ridge were covered with perennial plant growth, as opposed to a 25% cover obtained on an adjacent site unburned for 18 years. Herbaceous plant cover was not measured, but was more abundant on the burn.

The common Eriogonum fasciculatum (1,394/ha) and Lotus scoparius (845/ha), and uncommon Arctostaphylos glauca (5/ha) and Juniperus california (5/ha), along with two other species, comprised 14% of the unburned perennial cover. These species are incapable of resprouting after fire and were beginning to reappear as seedlings on the burn. Haplopappus linearifolius and Salvia apiana were also found reinvading the burn as seedlings, along with resprouts. Ceanothus crassifolius, which was not sampled in the unburned area, was returning in large numbers by way of persistent seeds on the burned ridge.

When the recovering plants are compared to the unburned areas and the preburn vegetational compositions, it appears as if this ecotone is fairly stable. For a few postfire years, some species fluxuate in numbers, with such species as Eriodictyon trichocalyx increasing to over 1,000 shrubs/ha from scattered individuals and dormant root systems, and with the dormant seeds of the short-lived Ceanothus crassifolius producing numerous seedlings, to cacti that are temporarily reduced by fire. But in general, the dominant species present have all quickly returned, or are in the process of regaining their former stature, with the desert and chaparral components of this ecotone not significantly decreasing or increasing in numbers.

POSTFIRE PERENNIAL PRODUCTIVITY

The above-ground productivity of the resprouting perennials was determined at the end of summer, fall, winter, and spring following the July fire.

Regrowth in the canyon produced 2,688 g/ha 2 months after the fire, increased to 88,179 g/ha after 4 months, decreased to 82,330 g/ha after 7 months, and then increased to 303,437 g/ha by the end of the year. Ridge productivity was 52 g/ha after 2 months, which increased to 12,814 g/ha after 4 months, with a decrease to 10,288 g/ha after 7 months, and then an increase to 99,824 g/ha after 10 months. The declines in growth at the end of the winter season were due to the deciduous nature of Acacia greggii and Chilopsis linearis, and foliage losses and growth suppression of other species due to a November blizzard, frequent frosts, and cold temperatures. Recovery on the ridge was slower than in the canyon, with the greatest increases in yields occurring in both sites during the warm spring months following the winter precipitation.

In the canyon, of the 17 perennial species present, 74% of the total yields were contributed by chaparral species, particularly Rhus ovata (42%), Quercus dumosa (19%), and Eriodictyon trichocalyx (9%), and 26% by desert species. On the ridge, of the 16 species present, 68% of the productivity was contributed by chaparral species, particularly Rhus ovata (42%), Quercus dumosa (20%), Cercocarpus betuloides (16%), and Yucca whipplei (10%), and 32% by desert species. The two most productive species in both areas were Rhus ovata and Quercus dumosa. Species with high numbers of resprouts per plant, which contributed to individual productivity, were Acacia greggii, Chilopsis linearis, Rhus ovata, Quercus dumosa, Yucca schidegera, and Y. whipplei (Tratz 1977).

HERBACEOUS PLANT PRODUCTIVITY

The above-ground yields of herbaceous

plants during the first year following fire were higher in the canyon (539,000 g/ha) than on the ridge (320,700 g/ha). When the total year's yields of perennials are compared to those of the herbs, herbs contributed a surprising 64% of the combined total of 842,437 g/ha in the canyon, and 76% of the total of 420,524 g/ha on the ridge. In other words, the annual herb productivity was almost 2, to 3 times that of the perennial plants.

Mass germination of herbaceous plants started in September, 2 weeks after the first rain, and reached maximum growth by mid-winter. Some of the first species to appear and flower were Erodium circutarium, Calyptridium monandrum, Boerhaavia wrightii, Amaranthus fimbriatus, Pectis papposa, Cryptantha sp., Bromus rubens. Later species to appear were Emmenathe penduliflora, Layia glandulosa, Eriophyllum wallacei, Amsinckia intermedia, Lotus tomentellus, Salvia columbariae, Sphaeralcea ambigua, Chorizanthe fimbriata, Eriogonum davidsonii, Oenothera caespitosa, Eriastrum diffusum, Phacelia ramosissima, Tauschia arguta, and Euphorbia setiloba. These species represent typical desert and chaparral winter annuals as well as fire followers. Although herb growth varies from year to year and burn to burn, its occurrence in this study provided a rapid-returning soil cover, erosion control, and wildlife foods and cover.

HERBIVORE UTILIZATION

The amount of each perennial plant species consumed by herbivores was calculated by multiplying the mean weight per cm of sprout by the mean difference in lengths between the browsed and unbrowsed sprouts, and by the total number of sprouts browsed. The plant materials consumed by wildlife are considered underestimates because some stems may have been eaten to ground level and missed, and other browsed stems may have recovered to full length by sample time.

Only 8 of the 20 species sampled in the canyon possessed evidence of browsing (Table 1). The most important of these were Quercus, Acacia, Rhus, Yucca schidigera, and Chilopsis. Herbivore utilization of these species varied from season to season, with the greatest amounts consumed in the fall. At that time, Quercus and Acacia were preferred, but their utilization declined as Quercus leaves and stems became tough, and Acacia spines hardened. Rhus, Chilopsis, and Hymenoclea reached their peak consumptions in winter in the canyon. Yucca schidigera and Eriodictyon were most heavily used by herbivores in the spring (table 1).

Table 1--Amounts of canyon and ridge perennial shrubs consumed by herbivores.

SEASON OF SAMPLE	SUMMER	FALL	WINTER	SPRING
MONTHS AFTER FIRE	2	4	7	10
SPECIES	grams per hectare			
CANYON				
Rhus ovata	27	175	795	175
Quercus dumosa	0	6,385	1,437	178
Acacia greggii	3	1,189	974	245
Chilopsis linearis	14	100	152	83
Hymenoclea salsola	0	3	24	31
Eriodictyon trichocalyx	+	8	+	18
Ribes quercetorum	0	0	1	0
Yucca schidigera	2	115	22	403
12 remaining species	0	0	0	0
Total	46	7,975	3,405	1,133
RIDGE				
Rhus ovata	0	2,691	2,502	702
Quercus dumosa	0	1,048	678	76
Acacia greggii	0	9	69	+
Cercocarpus betuloides	0	0	0	3
Yucca schidigera	0	178	+	10
Pellaea mucronata	0	1	0	0
Opuntia basilaris	0	0	0	15
14 remaining species	0	0	0	0
Total	0	3,927	3,249	806

On the ridge, only 6 of the 20 sampled species were browsed. Because of the delayed response of recovery on the dry ridge, browse plants were generally unavailable 2 months after the fire, as opposed to the canyon where they were almost immediately available and eaten. Rhus and Quercus were most heavily used in the fall on the ridge, with Rhus continuing to be the most important food for deer, desert bighorn sheep, and rabbits in the winter.

The low number of plant species used by mammals in the canyon and ridge is perhaps indicative of adequate amounts of preferred plant species. Less desirable plants were not touched. Larger amounts of perennial plants were consumed in the canyon (12,559 g/ha) than on the ridge (7,982 g/ha), both season by season and during the entire year.

When the consumed sprouts are compared to the total plant yields available, it is apparent that adequate browse was available for wildlife. This was true of the canyon growth during all seasons, but not for the ridge until the fall rains stimulated regrowth.

In the canyon, 2% of the total available plant productivity was used in the summer, 9% in fall, 4% in winter, and 0.4% in spring, for a year's total of only 4%. On the ridge, 8% of the total available growth was eaten during the year, with 31% of the fall, 32% of the winter, and 0.8% of the spring productivity being consumed. Apparently, increases in herbaceous plants, the addition of seedlings, and the hardening of shrub resprouts alleviated much of the browsing by spring.

These results, as well as direct observations, indicated that a number of herbivores were present and remained in the burned area, and that recovering shrubs provided adequate food for them, even during the first months after the fire. The key to the rapid recovery of plant foods was the presence of canyon-bottom plants or phreatophytes in contact with underground water. It appears that the herbivores of this ecotone were able to cope with the fire, adjusting to it, as their progenitors have undoubtedly done countless times before, responding to the burned landscape as a part of the vegetation cycle.

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A POLICY-ORIENTED SIMULATION MODEL OF DEBRIS PRODUCTION FROM A CHAPARRAL-COVERED WATERSHED[1/]

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Abstract: A policy-oriented computer simulation model was developed for estimating the cumulative volume of debris produced, in cu. yds./sq. mi., from 0.1 square mile watersheds along the southern flank of the Central San Gabriel Mountains. The model was constructed with a mathematical expectation formula that uses input data computed from equations fitted to nomogram curves from Ferrell's (1959) Report on Debris Reduction Studies for Mountain Watersheds. The computer model was used to evaluate the physical consequences associated with applying different fire management policies to these watersheds, including leaving them unburned, burning them on 15- and 25-year rotations and allowing each watershed to be burned in its entirety once in 50 years, and once every 20 years. The political implications of the simulation results were evaluated with a conceptual model that uses the resources people claim to link interest-groups to particular successional stages in brushland watersheds.

Key words: fire management policy, debris production, computer simulation, fire and fuel management.

INTRODUCTION

Purpose of the Study

Computer models of biophysical processes are usually designed to either probe natural phenomena to increase our understanding of their behavior, or to assist in making technical decisions about management practices. Rarely, if ever, are such models constructed to address broad policy issues.

When computer models are applied to resource management problems they are generally based on the assumption that society, or at least a management agency, has already decided upon an appropriate solution. All that remains is to determine the most effective

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1/ Presented at the Symposium on Environmental Consequences of Fire and Fuel Management in Mediterranean Ecosystems, Palo Alto, Calif. Aug. 1-5, 1977. The research leading to this report was supported by the OFFICE OF WATER RESEARCH AND TECHNOLOGY, USDI, under the allotment program of Public Law 88-379, as amended, and by the University of California, Water Resources Center, as a part of Office of Water Research and Technology Project No. A-058-CAL and Water Resources Center Project UCAL-WRC-W-499.

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and efficient way to use that solution to correct the problem. Computer models which address fire management for brushland watersheds in southern California are generally of this type. The problem is clearly specified as minimizing costs and losses associated with wildfires. The assumed solution is to suppress fires and break up the shrub cover with fuelbreaks and firebreaks that aid firefighters in confining fires within predetermined boundaries.

Decision-makers do not have computer models available that allow them to compare the effects of present policies with alternative solutions to southern California's fire management problem. Computer models generally address questions dealing with fire behavior and the optimal allocation of firefighting resources, including the placement of fuelbreaks and firebreaks. Outstanding examples of such models include Rothermel's (1972) wildland fire spread model, North's (1974) "decision-analysis" model and Omi's (1977) multiple regression analysis of fuelbreak performance. Although these computer models may provide knowledge essential for moving to non-traditional fire management policies, they do not provide decision-makers with information on the social benefits and costs of applying those policies, such as prescribed burning, to the brushland fire problem.

Since questions on how successfully one fire management policy works as compared to another are left unanswered by existing computer models; decision-makers can only update their information on how well the present policy is working today as compared to its past performance. All that changes is the technology used to carry out the present policy, not the policy itself. Fuelbreak size or placement may have changed and aircraft might be larger, more numerous or more strategically located, but the wisdom of pursuing an objective that requires the use of this technology is left unquestioned. Thus the decision-maker finds himself in the same unfortunate position as a researcher conducting an experiment without a control. There is no basis for making a comparison between policies. The experiment never changes, only the technique is different.

This study is a first step toward developing a policy oriented computer model which addresses the brushland watershed fire problem in southern California. The computer model is also based on a conceptual model which uses the resources people claim to link interest-groups to particular successional stages in brushland vegetation.

Hopefully such an approach to modeling will provide decision-makers with both information on the way biophysical systems respond to alternative management policies and how that response affects the lives of people.

The Fire and Debris Cycle

Fire is an integral part of southern California's brushland watersheds. Winter rains favor the growth of shrubs that blanket steep mountain slopes and the long, dry summer converts these brushlands into a continuous covering of energy waiting to be released. Fast moving foehn, or "Santa Ana", winds can spread fires occurring during fall months over hundreds of square miles. Whole watersheds may be stripped of their protective covering of vegetation. Soil and debris may be flushed out of stream channels by flood waters if a wildfire is followed by heavy rains. These sediments are then deposited on alluvial cones and in channel bottoms further downstream. Repeated fires and floods convey the sediments to the ocean and replace them with fresh material.

The heat produced by a wildfire stimulates the germination of dormant seeds and prepares a favorable seedbed for many brushland species (Stone 1953; Stone and Jurhen 1951; Quick and Quick 1961). Fire also induces sprouting in a number of shrub species. The new seedlings and sprouts of shrubs and the seedlings of perennial and annual herbs, rapidly replace the vegetative cover removed by fire. Up to ninety percent of the pre-fire shrub cover may be replaced within seven years, and full coverage is normally achieved in less than twelve years (Ferrell 1959).

Recovery of the vegetation on steep chaparral covered slopes does not stop erosion. Individual particles of sand, and rocks up to the size of small boulders, can roll downhill without the aid of rainfall. This process is known as "dry creep" and gravity is the only source of energy required (Rice and Krammes 1970). Some of this material may be stopped temporarily against the stems of shrubs, or in their litter and duff, but sparsely vegetated, unstable slopes continue to allow the free downward movement of particles (Rice and Krammes 1970). Thus debris gradually accumulates as cone shaped piles in sections of stream channels and builds up behind the stems of plants. When the vegetation reaches 20 to 40 years of age it is ready to burn and renew the cycle.

Chaparral Succession

Successional changes occur throughout the vegetation recovery period. These changes are not exactly the same in all southern California brushlands. As Hanes and Jones (1967) point out, the role of a species in chaparral succession must be considered in relation to the exposure of the site, age, and density of individuals present when burned, sprouting and seeding potential of the species, and many other variables. Nevertheless, a simplified version of chaparral succession can be represented in a generalized form.

Chaparral succession differs from the classic model that consists of a series of stages characterized by the replacement of one species by another. The post-fire sequence of vegetation changes in chaparral begins with some of the same species that comprise the mature plant association. Hanes (1971) refers to this process as "a gradual ascendance of long-lived species present in the pre-fire stand" and he calls it "auto-succession".

Succession in chaparral types dominated by chamise (Adenostoma fasciculatum) can be simplified into a generalized sequence of events indicative of successional processes operating in most southern California brushland watersheds. The fire event that initiates succession varies in its effects on different species. In general, chamise shrubs are reduced in number, but survivors produce enough sprouts to perpetuate this species as a dominant (Horton and Kraebel 1955). Seedlings also develop from chamise seeds after burning. Individuals of other shrub species, such as hoaryleaf ceanothus (Ceanothus crassifolius), often suffer 100 percent mortality when burned. However, ceanothus also produces seedlings during the first year after a fire (Horton and Kraebel 1955).

Although the composition of the shrub cover changes little throughout the successional process, the relative abundance of different species does change. For example, hoaryleaf ceanothus, deerweed (Lotus scoparius) and coastal sage subshrubs (Salvia spp.), continually die in the mature shrub cover and are not replaced by seedlings. Thus the number of shrubs gradually decreases during the second decade after a fire while total cover increases (Hanes 1971; Horton and Kraebel 1955). In addition, the loss of species from the shrub cover results in a gradual decline in the diversity of brushland vegetation as it grows older.

Perennial and annual herbs also occupy freshly burned sites in southern California brushlands. Dicentra chrysantha, Penstemon spectabilis and Helianthus gracilentus are perennial herbs which can remain after a fire until shaded out by a dense overstory of shrubs (Horton and Kraebel 1955). On the other hand, annual herbs may or may not remain in the vegetation during the full time necessary for shrubs to dominate the site. Some annual herbs can appear several years after a burn while others, such as Phacelia brachyloba, become established shortly after a fire and disappear within a few years (Horton and Kraebel 1955). Similarly, annual grasses, and such perennial grasses as Melica imperfecta and Stipa lepida, develop slowly, reaching their greatest abundance in 3 to 5 years after a fire, and diminish in importance as the shrub cover matures (Horton and Kraebel 1955).

CONCEPTUAL MODEL

Fire and Resource Use Conflicts

Some residents of southern California coexisted with the fire and debris cycle, and benefited from its effects, while others interrupted this cycle and, consequently, suffered regular and occasionally severe losses. Aboriginal people hunted deer and small mammals, and harvested the seeds of plants, that flourished after fire. These Aboriginal people had little incentive to control fire once it began burning. In fact, they had a strong incentive to start fires themselves since many of the essential resources obtained from their environment were produced with the aid of fire.

Spanish settlers also benefited from fire when their livestock grazed plants that grew on recently burned brushlands. However, Spanish settlers were concerned about the destruction of their buildings and crops, and most important, the unplanned loss of grass for their horses and cattle (Clar 1959). As a result, a conflict arose between aboriginal residents and Spanish settlers over the use and control of fires.

Since the late 1800's southern California's pleasant climate has drawn millions of people into the area. These people claimed many different resources from their environment. Some moved into the brush covered mountains and settled in portreros to raise cattle and sheep (Douthitt 1938b). Other people occupied the lowlands raising citrus and other agricultural crops on rich alluvial soils, and developing industries

along the coast. These people formed the nuclei of two groups which dominated fire management politics in southern California until the middle of the twentieth century.

Stockmen who settled in the mountains found potrero grasslands too small to support an economically sound livestock operation. Consequently, they supplemented portrero grazing with forage produced by periodically burning adjacent chaparral (Douthitt 1938a). Stockmen also burned brush to make it easier to move cattle from one canyon to another and to reduce the fire hazard (Nash-Boulden 1918). Thus stockmen depended upon the use of fire for their livelihood.

On the other hand, lowland settlers had no need to use fire and, in fact, to them fire was purely a destructive process. Fires burning out of the mountains nearly destroyed the cities of San Diego and San Juan Capistrano (Barrett 1935). Settlers living on alluvial fans and flood plains found that destructive floods and debris flows were associated with wildfires and heavy rainfall (Mulford 1942). Finally, lowland settlers also experienced a number of occasions when a reduction in streamflow was associated with wildfires in brushland watersheds (Barrett 1935). This problem was further compounded by the filling in of critically important reservoirs with debris washed down from recently burned brushlands.

The conflict between mountain and lowland residents in southern California over the use and control of fire was symptomatic of a more basic relationship. The real issue of concern was the role fire played in changing the resources people claimed from the land. Lowland residents wanted a secure supply of freshwater and protection from floods, mudflows and destruction of property by fire. Stockmen wanted to protect their property from fire too, but they also wanted enough grass for their cattle to graze and fewer obstructions to the movement of their livestock.

Today there is no longer a relatively clear division between mountain and lowland interest-groups on fire issues. However, the traditional downstream water users, debris protection and livestock interest-groups continue to be politically active in fire management politics. Of course, deer hunters have been involved in fire management politics for many years. They favor the use of fire to produce more browse and hence, a larger population of deer. Since deer hunters come from both the mountains and lowland, they have always blurred the distinction in positions held by interest-groups from these two areas. Nevertheless, this dichotomy is even less clear today with the advent of new interest-groups.

Environmental groups are not new but they have only recently gained influence on fire management issues. Environmentalists are advocating a position close to that of stockmen even though most of them come from lowland areas. However, they are not interested in the production of forage for livestock. Their interest is focused on restoring fire to brushland watersheds because it is the process that created and maintained these watersheds before European man's intervention.

Stockmen now share the mountains with large numbers of suburban homeowners who do not depend on livestock for a living. These new brushland residents are primarily concerned about protecting their homes from fire, and living in a pleasant rural environment. In general, mountain homeowners appear to neither strongly favor nor strongly oppose the use of fire to reduce fuels. Their main concern is solving the fire problem and not the method used to accomplish that goal.

Another interest-group that recently emerged is the sand and gravel industry in Los Angeles County. This industry is facing a potential shortage of debris. In fact, most local sources of sand and gravel production are expected to end by 1995 (Davis 1976). This problem is compounded by a significant increase in the use of debris for construction purposes. Furthermore, long travel distances will be necessary to bring material in from new quarry sites (Davis, n.d.). Therefore, interest is developing in processing the sediment captured behind flood control structures (Davis, n.d.). Since fire, especially when followed by heavy rainfall, can contribute to the production and transportation of debris, it is reasonable to assume that the sand and gravel industry will not favor the complete elimination of fire from brushland watersheds.

Linking Interest-Groups to Successional Stages

The various interest-groups involved in fire management politics are extremely diverse and difficult to deal with if they are categorized according to the resources they claim from the land. Stockmen claim forage for their cattle and sheep. Urban residents in the lowlands claim large quantities of fresh

water and a place to live that is secure from floods and debris flows. Deer hunters claim browse and the deer it feeds. Rural homeowners claim a place to live that is free from destruction by fire and surrounded by a pleasant natural environment. Sand and gravel interests claim debris that moves down out of the watersheds. Environmentalists claim the restoration and maintenance of biophysical processes free from man's intervention, and the environments that result from the operation of those processes.

An alternative way to categorize interest-groups is to couple them to particular features of brushland watersheds that directly or indirectly support the resources they claim. This approach has two advantages. First, it simplifies the diversity of resource claims by tieing them to something they share in common. Second, it locates those resources within a fixed geographical area which, in most cases, is more easily controlled by resource management agencies.

Groups involved in fire management problems in southern California share a common interest in the condition of the vegetation that grows in brushland watersheds. Certain vegetation conditions benefit the resource claims of some interest-groups and are a detriment to others. Furthermore, different vegetation conditions can also be thought of as stages in a successional process. The point is that vegetation changes over time, but the resources interest-groups identify are usually fixed to particular stages in the successional process. Thus the replacement of one successional stage by another often results in one interest-group being favored over another.

An illustration of how this model can be applied to southern California brushland watershed fire management is shown in figure 1. With this diagram the claims of stockmen can be shifted from forage as a resource to the second and third stages of succession where forage is produced. Similarly, deer hunters are linked to the second, third and fourth successional stages because the diet of deer includes both the sprouts of young shrubs and herbaceous forage (Biswell 1974). Rural homeowners (fire protection interests) are linked to early successional stages because these vegetation conditions contain the

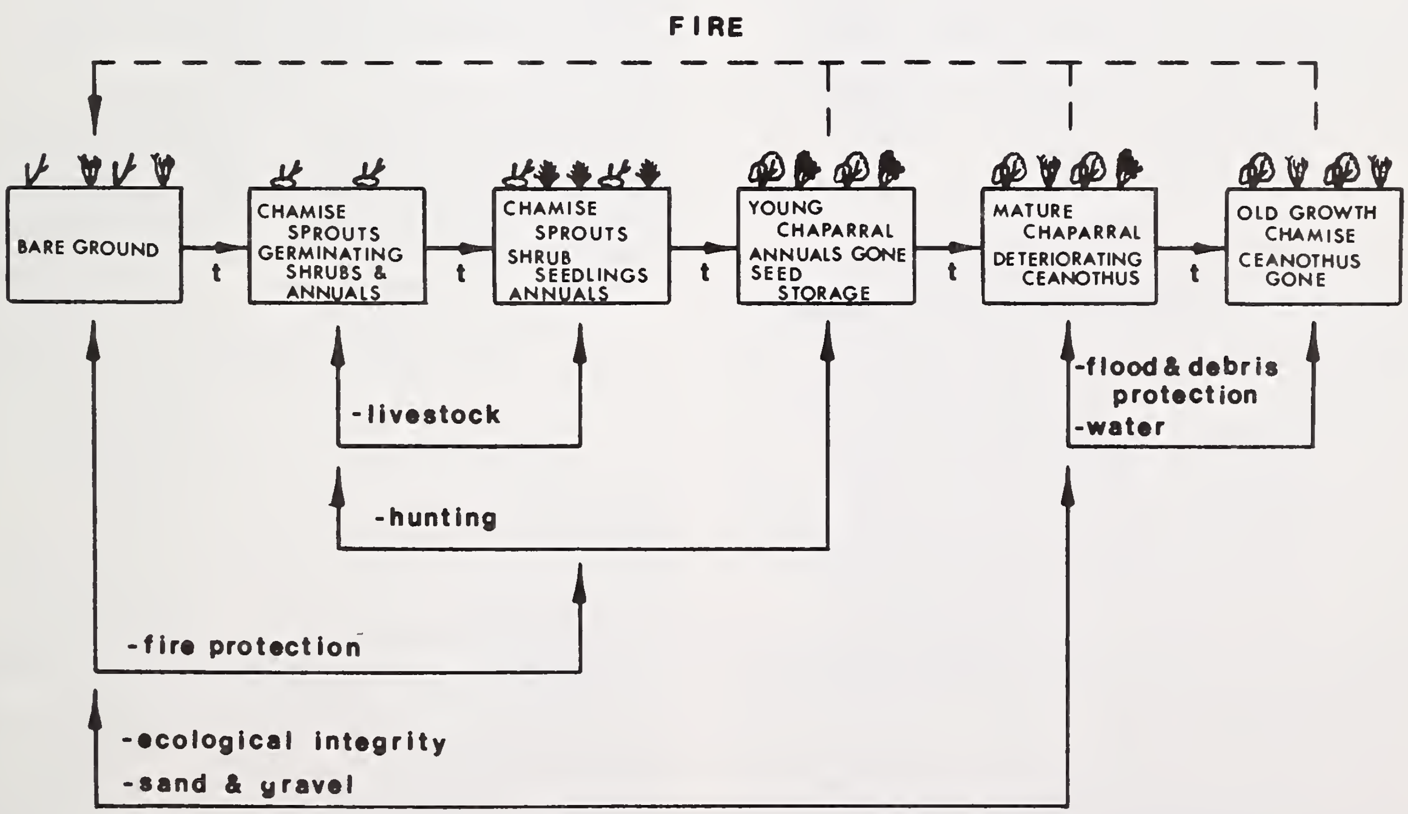

Figure 1. Generalized successional sequence for chamise-chaparral vegetation showing how the resources claimed by interest-groups can be used to link these groups to particular successional stages.

least amount of fuel. Environmentalists (ecological integrity interests) are linked to all successional stages, except the abnormally old stages, because all of these stages existed in one or more elements of the vegetation mosaic produced by periodic wildfires.

Sand and gravel interests are also linked to the same successional stages as environmentalists, but obviously for different reasons. Sand and gravel is flushed out of stream channels when vegetation is removed, but it must also have time to accumulate before it is available for movement. Thus early successional stages encourage heavy runoff and the transportation of debris to lowland areas, while later stages allow debris to accumulate and be stored until fire re-initiates the successional process.

Downstream water use, and flood and debris protection interest-groups are also linked to late successional stages. When a steep watershed with shallow soil is fully covered by vegetation, rainwater, instead of rapidly moving downhill as surface flow, filters into the soil and parent material where it gradually flows out to streams and accumulates in aquifers. Even though some water is lost to transpiration, this loss is negligible compared to the benefits of having subsurface water during summer droughts. Debris protection interests are also favored by a dense covering of vegetation because the lower peak flows of streams transport less debris to lowland areas.

The conceptual model pictured in figure 1 also illustrates which interest-group claims might be compatible, and which claims are not compatible on the same area of land. For instance, the resource claims of flood and debris protection, and downstream water use interests are clearly incompatible with the resource claims of stockmen and deer hunters. Since a brushland watershed cannot be maintained in both an early and a late successional stage at the same time, political conflict between interest-groups that claim one or the other stage is inevitable. This simple relationship helps to explain why stockmen and lowland residents have been in conflict over the use of fire for over half a century.

The seemingly irreconcilable conflict between interest-groups favoring stages at opposite ends of the successional sequence can also be seen as resolvable if figure 1 is interpreted correctly. For example, if each group is willing to accept having part of a watershed represented in the appropriate successional stage then both groups may be satisfied simultaneously. In other words, each interest-group must accept a suboptimal situation for itself in order to optimize the sum of the benefits to both interest-groups. This is the old idea, but compromise has proven successful in many other conflicts.

The compromise presented above can be carried to its logical conclusion for the case involving all interest-groups concerned with fire management policy in brushland watersheds. What is required to provide a suboptimal solution to each interest-group is to allow succession to proceed for a fixed interval of time in any one location within a watershed, and then reactivate the process with a disturbance. Thus a watershed would be composed of a mosaic of successional stages, and individual stages would rotate around the watershed over time. Obviously, if every major interest-group can be linked to one or more successional stages, then managing brushland watersheds in a manner that permits all stages to be represented would at least partially satisfy all resource claims.

Of course, operationalizing this approach would not be as easy as it might appear, even leaving political questions aside. The number and size of each successional stage represented in a watershed would have to be determined on the basis of the total effects all stages produce, not just their individual effects. That is, the biophysical, social and economic outcomes produced from the watershed as a whole, for each selected combination of successional stages, would have to be evaluated.

COMPUTER MODEL

Policies Assessed

The policy oriented computer model presented here is designed to look at several alternative approaches to managing fire within a single watershed. Policies are evaluated in terms of a single variable -- debris production -- which integrates the consequences of each policy for the watershed as a whole. The policies selected are (1) leaving the watershed unburned, (2) burning the watershed on a 25-year rotation, and (3) burning the watershed on a 15-year rotation. In addition, an estimate is made of the consequences of leaving the watershed unburned while assuming that (1) one fire accidentally burns the whole watershed during the planning period, (2) one fire accidentally burns the whole watershed during the

planning period followed by a 50-year flood, (3) a 50-year flood precedes a fire that accidentally burns the whole watershed during the planning period, and (4) a fire burns the whole watershed every 20 years during the planning period.

Study Area

This study is based on the central portion of the southern flank of the San Gabriel Mountains. These mountains are composed of faulted metamorphic and granitic blocks thrust up during the Pleistocene and disected by deep canyons separated by sharp ridges. They rise to an elevation of 10,080 ft. (3,070 m), extend in an east-west direction a distance of 60 miles (97 km) and are 20 miles (32 km) wide. Their underlying rock is highly fractured and deeply weathered. Nevertheless, soils are shallow and easily eroded due to the steepness of the terrain. Most drainages are completely developed with dams to store water and debris for the Los Angeles Coastal Plain.

The climate of the San Gabriel Mountains is classified by the UNESCO Arid Zone Research Team (1963) as xerothermomediterranean because it is similar to the climate of the Mediterranean Sea Region. Reimann and Hamilton (1959) report that over 85 percent of the total annual precipitation occurs from December through April, most of which comes from a few intense storms.

The steep slopes, unstable soils, and heavy winter rains found in the San Gabriel Mountains, when combined with the removal of vegetation by fire, can produce single storm debris flows in excess of 100,000 cubic yards per square mile of watershed (Ferrell 1959). The potential for volumes of material of this magnitude flowing out of the mountains is particularly serious because thousands of homes and businesses are located on the alluvial fans that were built up by past debris flows.

Source of Data

The numerical data for this study were obtained from Ferrell's (1959) Report on Debris Reduction Studies for Mountain Watersheds. Although the functions developed in Ferrell's (1959) report have not proven to be accurate for predicting debris flows from particular watersheds under given conditions, they are considered satisfactory for making relative comparisons between policy options.[3]

The subset of these data selected for use in the computer model came from the 52 watersheds located in the Central San Gabriel Mountains. The total area involved is 34.88 square miles and the mean drainage area is 0.67 square miles.

Model Development

The computer model is based on a simple mathematical expectation formula that utilizes, as input data, the results of a series of prior calculations performed in the model. The expected cumulative debris produced in cubic yards per square mile from a watershed of a given size is expressed as

$$[1] \qquad E(D) = \sum_{i=1}^{N} \sum_{j=1}^{50} d_{ij}\, P(d_{ij})$$

where i = years simulated; j = runoff levels for storm classes occurring over a 50-year period; d_{ij} = debris production associated with a particular runoff level for a watershed with specified characteristics and $P(d_{ij})$ = probability a storm producing a particular volume of debris will occur in any given year. Thus the expected volume of debris produced for one year is summed for the number of years desired in the simulation.

Debris production values used in Eq. [1] were taken directly from Ferrell's (1959) equation

$$[2] \qquad d = \frac{35,600\, Q^{1.67}\, R^{0.72}}{(5 + V)^{2.67}}$$

where d = debris production in cu. yds./sq. mi.; Q = peak runoff, expressed in cubic feet per second per square mile, resulting from the maximum 24-hour rainfall of a given storm; R = relief ratio of the watershed; and V = vegetation index. The relief ratio (a measure of the relative steepness of a watershed) remained constant for all calculations with a value of 0.288, the mean for Central San Gabriel Mountain watersheds.

The peak runoff values used in Eq. [2] were obtained by fitting linear regression equations to the curves in Ferrell's (1959) nomogram that convert maximum 24-hour rainfall values to runoff. The nomogram curves selected were for a 0.1 square mile watershed. This is the only watershed size which was analyzed with the computer model.

[3] Personal communication with Mr. J. D. Davis, Los Angeles County Flood Control District, July, 1977.

The variable in Eq. [2] of primary interest in this study is the vegetation index. This index is an expression of the effectiveness of a particular vegetative cover to deter erosion and it can be computed from the following equation:

$$[3] \qquad V = \frac{(\Sigma\ I_1\ P_1 + \Sigma\ I_2\ P_2)}{100}$$

where I_1 = number of index points assigned to a vegetation type; P_1 = percent of the total watershed covered by that vegetation type; I_2 = number of index points assigned to a particular percent cover; and P_2 = percent of the total watershed in that percent cover. Only pure chamise-chaparral vegetation is used in the computer model. The vegetation index for a 100 percent cover of chamise-chaparral is 25.0. This is the value used in the computer model for unburned watersheds.

Vegetation indexes are also varied to reflect cover conditions on a watershed burned on 15- and 25-year rotations. In other words, a watershed is divided into 15 or 25 compartments which differ in the amount of cover they contain. For example, assuming it takes 12 years for the vegetation to reach 100 percent cover after a fire, a watershed that is burned on a 15-year rotation would have 12 compartments in various stages of recovery and 3 compartments with maximum cover. Thus the vegetation index for a 15-year rotation burn is 19.58, and for a 25-year rotation burn it is 21.76.

When an entire watershed is burned the vegetation index is calculated as if the watershed as a whole is a single compartment. Therefore, after a fire event occurs, the vegetation index drops to 5 and then it increases over time as the cover increases. The index remains constant when the vegetation cover reaches 100 percent. This process is repeated if multiple fires occur in the watershed during the time period simulated with the computer model.

Simulations that include a 50-year flood are handled the same way as other simulations except that a flood event is allowed to happen during a given year. That is, the probability that a rainfall level which normally occurs only once in 50 years is set equal to 1.0 for the particular year in which a 50-year flood is assumed to occur.

The antecedent wetness of a watershed is also considered in the simulation of debris production. The volumes of debris produced using Equation [2] are based on the assumption that a watershed is 100 percent saturated. Therefore, these values are scaled down to provide volumes of debris for watersheds which are less than saturated.

Maximum possible debris volumes calculated for saturated watersheds with Eq. [2] are adjusted downward by multiplying them with a coefficient that determines the fraction of debris production remaining. The equation for finding this coefficient for a 50 percent watershed saturation level, the only saturation level used in this study, is expressed as

$$[4] \qquad C = 0.32F^{0.57}$$

where C = a decimal fraction between zero and 1.0 and F = a dimensionless index used by Ferrell (1959) to describe one of the ordinates of his nomogram. The F index is computed from the equation

$$[5] \qquad F = \frac{3.5\ Q^{0.7}R^{0.3}}{(5 + V)^{1.12}}$$

where Q = peak runoff; R = relief ratio of the watershed; and V = vegetation index. Thus, for a maximum 24-hour rainfall of 10 inches, a 0.1 square mile watershed, with a vegetation index of 24 and a relief ratio of 0.288, would produce about 41,500 cu. yds./sq. mi. of debris if the watershed is 100 percent saturated. The F index from Eq. [5] equals 3.728. If the watershed is 50 percent saturated the decimal fraction from Eq. [4] equals 0.677 and the volume of debris produced from the watershed is reduced to 28,115 cu. yds./sq. mi. All of these values closely approximate those found using Ferrell's (1959) nomogram.

RESULTS

Output from the computer model shows that distinct differences do exist between the effects resulting from applying the fire management policies examined in this study. As expected, the cumulative volume of debris produced is lowest for a chamise-chaparral covered watershed that is left unburned (fig. 2). This relationship remained the same when the watershed was subjected to a 50-year flood during the period of time simulated (figs. 3 and 4).

As figure 2 shows, the 25-year rotation burn policy produced about 31.5 percent more debris than a comparable area using an unburned watershed policy. When a watershed, managed with the 25-year rotation burn policy was also subjected to a 50-year flood during the simulation, the absolute volume of debris

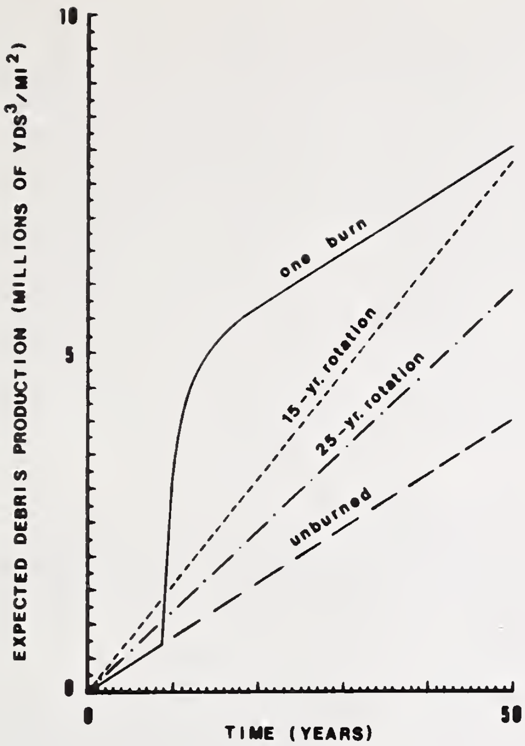

Figure 2. Expected debris production from a 0.1 sq. mile unstabilized watershed covered with chamise-chaparral.

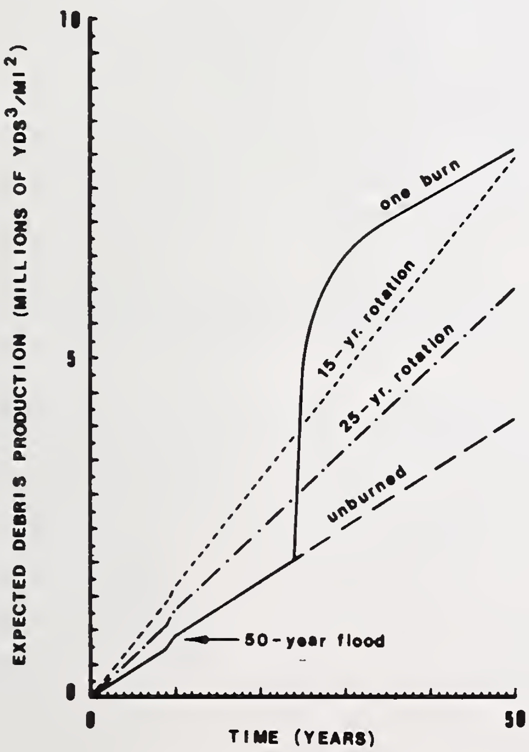

Figure 3. Expected debris production from a 0.1 sq. mile unstabilized watershed covered with chamise-chaparral. Simulation includes a 50-year flood in year 10 and a once-in-50-year watershed burn in year 25.

produced was only 1.2 percent greaer than the same policy produced in a comparable watershed which did not have a flood (figs. 2 and 3). The 25-year rotation burn policy also produced the least amount of debris relative to all other fire management policies, except the one that left a watershed unburned for the same length of time (figs. 2, 3, 4, and 5).

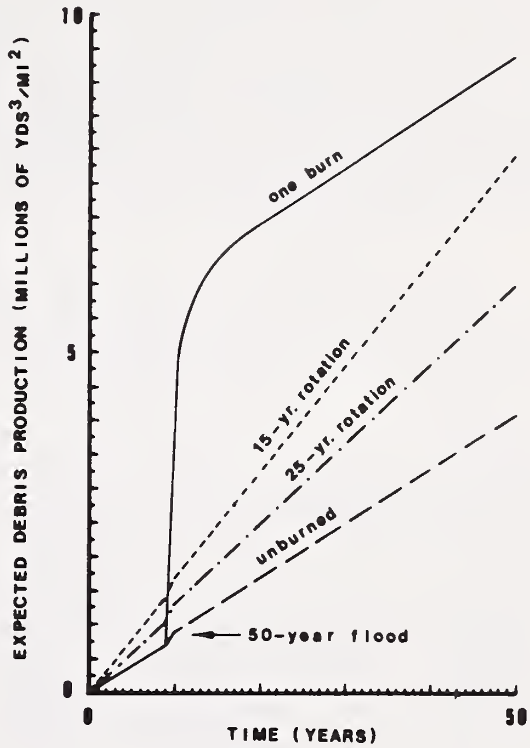

Figure 4. Expected debris production from a 0.1 sq. mile unstablized watershed covered with chamise-chaparral. Simulation includes a 50-year flood and a watershed burn in year 10.

An interesting outcome of the simulation was the closeness in absolute volume of debris produced for both a 15-year rotation burn policy, and an unburned watershed policy that did not succeed in preventing one fire from burning the whole watershed during a 50-year period. In fact, this difference, as shown in figure 2, is only 3.6 percent. The greater volume of debris was produced from the policy that resulted in a single fire burning the whole watershed, but the difference is not significant. Figure 3 shows that this difference is also insignificant when a 50-year flood occurs prior to the burning of the watershed. However, if a 50-year flood happens to hit in the winter following a fire that burns a whole watershed, the volume of debris is 15.3 percent greater than would be produced using a 15-year rotation burn policy. In addition, a 15-year rotation burn policy spreads debris production out over a longer period of time so that no single debris flow is large. In contrast, the policy in which the whole watershed burns results in the water-

shed generating most of its debris in one event.

Ferrell (1959) reported that each watershed in the frontal zone of the Central San Gabriel Mountains burned with an average recurrence interval of 20 years. Although the data used in his study applied to the period between 1907 and 1956, an examination of the Angeles National Forest Fire Atlas indicated that this recurrence interval has not changed and can be extended to 1975. Consequently, a 100-year simulation run was made that mimics this 20-year fire recurrence interval. The results are shown in figure 5.

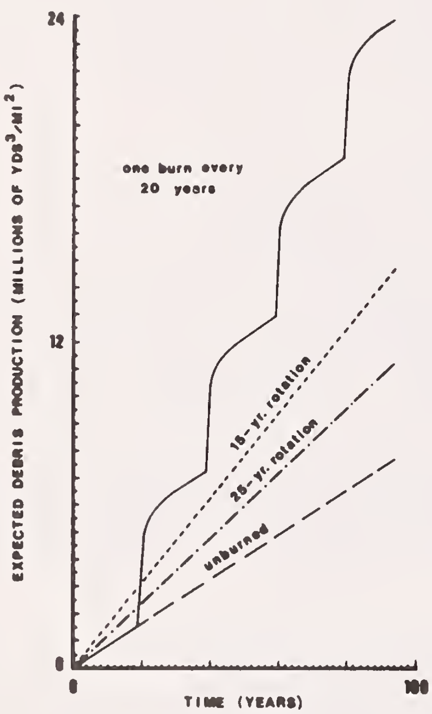

Figure 5. Expected debris production from a 0.1 sq. mile unstabilized watershed covered with chamise-chaparral. Simulation includes a watershed burn every 20 years.

The effects of a 20-year fire recurrence interval are dramatic (fig. 5). Each new fire adds significantly to the total volume of debris produced from a watershed. The absolute volume produced at the end of a 100-year period is 38.4 percent greater than a 15-year rotation burn policy, 53.5 percent greater than a 25-year rotation burn policy and 68.1 percent greater than the intended policy of leaving the watershed unburned.

CONCLUSIONS

Several conclusions can be drawn from the results of the computer model simulations when they are combined with the conceptual model that links interest-groups to successional stages. First, the curves generated by the model are consistent with the view that flood and debris protection interest-groups are favored by a policy that leaves a watershed unburned. However, under actual conditions this policy is difficult to implement. Numerous studies show that fires do burn brushland watersheds in spite of the enormous efforts made by fire control agencies to stop them (Countryman 1974; Green 1977; Omi 1977; Philpot 1974). Thus flood and debris protection interests appear to be more vulnerable to losses, under the current policy of attempting to keep watersheds unburned, than they would be from either a 15- or a 25-year rotation burn policy.

One solution to the problem faced by flood and debris protection interests, which is presently in use, is to construct debris basins and dams on the assumption that fires will continue to occur. Unfortunately, the volume of material produced by these watersheds is greater than the capacity of all the Los Angeles County Flood Control District's structures (Davis 1976; Ferrell 1959). Furthermore, a number of watersheds remain unprotected by such structures because of economic and technical constraints (Davis 1976). Consequently, the needs of flood and debris protection interests are best served by augmenting existing protective devices with a rotation burn policy that generates a lower absolute volume of debris than the current policy, and does so with debris flows that are consistent and predictable.

Sand and gravel interest-groups also seem to be better off with a rotation burn policy because debris flows are predictable. The present policy of suppressing all fires is producing a larger absolute volume of debris than a rotation burn policy, but those high volumes of debris are coming out of the watersheds in a few large flows. The debris basins that accumulate this material must be cleaned out rapidly to prepare for the next flood. This practice is inconsistent with the sand and gravel interest's requirement for a constant and dependable supply of material.[4/]

4/ Personal communication with Mr. J. D. Davis, Los Angeles County Flood Control District, November, 1976.

In those situations where water production cannot be increased by removing vegetation, because of steep slopes and shallow soils, downstream water use interests are clearly better off with an unburned watershed policy. However, the lack of success in stopping wildfires may or may not be working against water use interests. Reservoirs periodically fill with large volumes of debris but, in many cases, this debris is quickly removed. Nevertheless, the cost of debris removal is high. Similarly, a denuded watershed loses much of its water to surface flow, yet these losses might be relatively unimportant in the long run because the period of time between fires could be long enough to allow acquifers to recharge.

As figure 1 illustrated previously, no other major interest-group involved in southern California fire management politics is favored by an unburned watershed policy. Fire protection interests could be an exception, but until wildfires are eliminated they will still be safer if their property is not surrounded by large volumes of fuel.

In the ideal situation, where intended results and the actual results coincide, policies that favor fire, flood and debris protection interest-groups are clearly detrimental to the interests of stockmen, hunters and environmentalists. However, current technology has not succeeded in achieving the objective of keeping fire out of brushland watersheds, and some investigators believe that this objective is unrealistic (Countryman 1974).

Periodic wildfires have created a mosaic of successional stages on the brush-covered mountains of southern California. Therefore, the current, but unsuccessful, policy of leaving watersheds unburned, although not intended, is providing all major interest-groups with some benefits. However, since the fires that escape early suppression often burn whole watersheds, the unintended benefits derived by stockmen, hunters and environmentalists are being paid for through the heavy losses incurred by fire, flood and debris protection interest-groups, and possibly by downstream water use interests as well.

The policy-oriented models and simulations presented in this study suggest that a compromise policy of burning on a rotation basis, <u>within</u> watersheds, would reduce wildfire losses <u>below</u> levels now experienced using the current unsuccessful policy of attempting to keep all fires out of brushland watersheds. These models also show that, in theory, the diversity of successional stages generated by a rotation burn policy would provide benefits to all major interest-groups affected by fire management policies in southern California.

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THE GEOGRAPHY OF FIRE AND BIG-CONE DOUGLAS-FIR, COULTER PINE AND WESTERN CONIFER FORESTS IN THE EAST TRANSVERSE RANGES, SOUTHERN CALIFORNIA[1]

Richard A. Minnich[2]

Abstract: Three vegetation types in the eastern Transverse ranges of Southern California--big cone Douglas-fir, Coulter pine, and western conifer forests--are characterized by contrasting fire regimes which reflect differences in the physiognomic relationship between dominant coniferous trees and associated hardwood evergreen sclerophyll shrub and woodland vegetation, and the topography in which they are found. The frequency of fire events lethal to conifers in each type is found to reconcile with the time required for their maturation to a level equivalent to nearby stands with no recent history of deforestation. Their present distributions in the area appear to reflect a selective influence of fire on conifer mortality observed in recent fires from remotely sensed aerial photography.

Key words: Fire, vegetation dynamics, remote sensing, southern California conifer forests.

INTRODUCTION

The study of the role of fire in different plant communities is a two-way street. Plants are both fuels which carry fire and "species" adapted to it. Thus, fire may influence plant community structure floristically because of the varying adaptation of individual species. Similarly, as fuels, the productivity and geometric arrangement of plants, may affect the frequency and intensity of fire.

In southern California mountains, where summer drought is a climatic norm, fires burn large areas of wildlands each year. Fire frequency and intensity, however, varies geographically with changes in climate, topography elevation, and exposure to the Pacific Ocean. The influence of fire on conifer forests in the eastern Transverse Ranges (San Gabriel and San Bernardino mountains), an area of impressive topographic and elevational contrasts, was evaluated comprehensively from contemporary and historical aerial photographic coverage for the period 1938 to 1975 (Minnich, dissertation research). Analysis of vegetation changes of several conifer forest types suggests that the rates of deforestation and post-fire regrowth of each are different, depending largely on the importance of evergreen shrub and woodland sclerophyllous vegetation, and the topography in which they are found. In general it was found that conifers well adapted to fire (fast post-fire regeneration) are also destroyed by fire; species poorly adapted (slow post-fire regeneration) tend to directly survive fire, or are distributed in areas having a very low fire frequency.

In this presentation, three conifer forest types--big cone Douglas-fir, Coulter pine, and western conifer forests--are discussed as a demonstration. Although these species exist in a similar regional setting (mesic Pacific slopes of the eastern Transverse ranges, annual precipitation 600-1000 mm.), their distributions and fire response are quite divergent.

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[1] Presented at the Symposium on Environmental Consequences of Fire and Fuel Management in Mediterranean Ecosystems, Palo Alto, Calif., Aug. 1-5, 1977.

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The role of fire in these types is briefly discussed by analysis of their physical appearance, combustion, and post-fire regeneration. These data are compiled primarily from color infrared aerial photography and field transects.

METHODOLOGY

The vegetation of the eastern Transverse ranges are mapped from vertical Kodak Ektachrome Infrared photography ranging in scale from 1:20,000 to 1:60,000 (Minnich 1974). On figure 1 is a profile of vegetation in the eastern San Bernardino mountains as an illustration of typical plant communities and the classification. Vegetation types are defined as overlapping floristic units (single and multiple species sets) identified from the film and mapped where their cover exceeds 10% for conifers and 20% for all other species. Types are divided into three physiognomic classes: shrubs, woodlands and coniferous trees. Letter symbols are assigned to each and combined on the profile where sympatry exists between types of different physiognomic classes. Types within a physiognomic class are divided at the point of equal abundance. The order of symbols makes priority of conifers over oak woodlands and brush. Quantitative data on vegetal cover characteristics are evaluated at 700 locations on aerial photography and summarized according to vegetation type. Shrub cover data is summarized from 616 ground plots surveyed in 1929 as part of a general survey of California vegetation by the California Forest and Range Experiment Station (VTM Survey). Except in areas of deforestation, the plots are found to correlate with the vegetation map at a 93% level of confidence.

The geography and rates of deforestation in conifer forest are evaluated by the comparison of color infrared photography flown before and after five recent fires. The aerial extent of conifer survival is determined by mapping the extent of red record (living foliage) in post-burn imagery as an overlay to vegetation mapped in pre-burn imagery. The burning mosaic is sampled for slope class and slope exposure in the same manner as the vegetation map (Minnich 1973).

Post-fire vegetation recovery is determined from 228 field transects in areas of deforestation and summarized according to vegetation type.

DESCRIPTION OF VEGETATION TYPES

The floristic composition and physiognomic structure of big cone Douglas-fir, Coulter pine and western conifer forests are markedly different (see table 1).

Big cone Douglas fir (Pseudotsuga macrocarpa, Bs) forests are found mostly on precipitous slopes, cliffs, and canyons between 900 and 230 m. elevation throughout the eastern Transverse ranges. At lower elevations

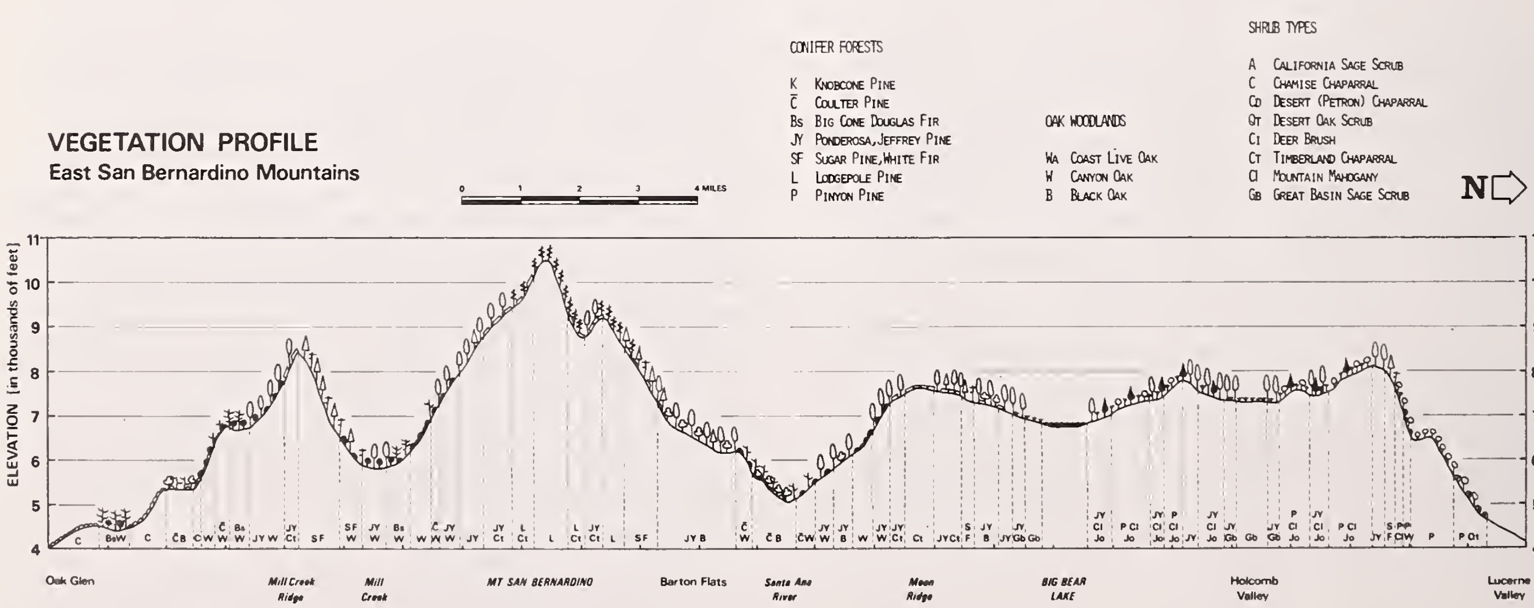

Figure 1--Vegetation profile: eastern San Bernardino mountains

Table 1--Physiognomic characteristics of vegetation types

Type	VTM Plots			Aerial Photo Sample		
	Mean Shrub	Shrub 1/ biomass	Percent conifers 24" d.b.h.	Total Cover	Total Cover	Canyon oak Cover
$\bar{C}$C	84	heavy	0	79	13	0
$\bar{C}$W	22	medium	16	80	25	23
$\bar{C}$B	34	light	26	46	26	5
BsW	13	light	52	83	41	56
JY	6	none	51	32	30	0
JYB	6	none	46	41	35	1
JYW	27	light	15	50	21	25
JYCl	11	light	53	45	23	0
JYCt	41	light	48	62	25	0
SFCt	34	light	42	60	26	0
SF	7	none	36	41	38	0

1/ Shrub cover X mean shrub height

populations are extremely disjunct, surrounded by extensive areas of chamise chaparral. Above 1300 m , stands are more widespread, sometimes covering entire slopes, particularly in the more precipitous San Gabriel mountains west of Cajon Pass. Canyon Oak (*Quercus chrysolepis*) is sympatric with all big cone Douglas-fir stands (BsW) and usually occurs in abundance. Together they form a two-layered contiguous forest consisting of an undercanopy of robust, often single trunked canyon oak trees with crowns 5 to 10 m above the ground, and an overstory of taller big cone Douglas-firs 25 to 40 m in height. The trunk diameter of a majority of trees exceeded 24 inches (0.6 m). Most stands are surrounded by chaparral but chaparral is seldom found within them, except for canyon oak reproduction and occasional *Ceanothus integerrimus* thickets.

The elevational range of Coulter pine (*Pinus coulteri* $\bar{C}$) is about the same as big cone Douglas-fir. In contrast, however, this species occupies smooth, steep slopes and ridges and is confined to the San Bernardino mountains east of Lake Arrowhead. Coulter pine stands are associated with a greater diversity of vegetation. Stands at lowest elevations are also scattered about in small, disjunct populations emerging above contiguous stands of chamise chaparral ($\bar{C}$C) dominated by *Adenostoma fasciculatum*, *Arctostaphylos glandulosa* and *Quercus wislizenii*. More continuous stands at higher elevations are associated with canyon oak (*Quercus chrysolepis*) which appear as large, multi-trunked shrubs emerging out of chamise chaparral ($\bar{C}$W). The cover provided by canyon oak, however, is normally much less than for big cone Douglas-fir stands. Coulter pine is also sympatric with black oak (*Quercus kelloggii*, $\bar{C}$B). a winter deciduous hardwood tree, on mostly old erosion surfaces. The shrub understory of Coulter pine--black oak forests usually consists of an open cover of shrubs including *Arctostaphylos pringled*, *A. pungens*, and *Ceanothus integerrimus*. Most Coulter pines sampled in the VTM survey were rather juvenile as nearly 75% of trees counted had diameters less than 12 inches (0.3 m).

Western conifer forest, occurs primarily above the chaparral belt between 1500 and 2700 m elevation and is found on all slopes and exposures. A floristically rich forest, the dominant species--Ponderosa pine (*Pinus ponderosa*), Jeffrey pine (*P. jeffreyi*), white fir (*Abies concolor*) and sugar pine (*P. lambertiana*) may be found together in many areas of the forest. Ponderosa and Jeffrey pine, however, a generally dominant (JY) except on steep north facing slopes where sugar pine and white fir prevail (SF).

In contrast with previous vegetation types, the biomass of the conifers is much greater than hardwood sclerophylls. Forests are mostly open, consisting of widely spaced trees 15 to 40 m tall with the crown undercanopy beginning 5-15 m above the ground.

Western conifer forests are associated with a diverse assemblage of shrub and woodland vegetation, whose biomass is relatively scant because of their small size and discontinuous

cover. The greatest biomass "shrub" is Canyon oak (Quercus chrsolepis) whose distribution extends upslope into western conifer forests from the chaparral belt. Other shrub and woodland types include timberland chaparral (Arctostaphylos patula, Ceanothus cordulatus, Castanopsis sempervirons, JYCt, SFCt), mountain mahogany (Cercocarpus ledifolius, JYCl) deer brush (Ceanothus integerrimus, JYCi), Great Basin sage (Artemisia tridentata, Chrysothamnus nauseosis, JYGb), and black oak (Quercus kelloggii, JYB). In general the importance of hardwood species is inversely proportional to conifer cover. Unlike chamise chaparral, however, these types with the exception of canyon oak are only locally dominant and rarely contain equivalent biomass.

FIRE MORTALITY

Cursory examination of fire maps interpreted from color infrared aerial photography (see sample, figure 2), show a mosaic of vegetal denudation and survival which in part patterns itself without regard to the distributions of vegetation types and concomitant changes in fuel structure. This of course is to be expected because the process of combustion operates under a variety of abiotic factors, notably fire weather and topography, in addition to the fuel content and structure of the vegetation. During the course of a fire, the atmospheric environment is constantly changing and fire response expressed in the rate of liberation of stored energy in the vegetation may vary in orders of magnitude with minor fluctuations in the horizontal wind field and atmospheric stability (Countryman 1964).

The "fire storm" is the most outstanding example. In circumstances of low vertical wind sheer and conditional instability, an updraft of superheated air generated by the fire develops into a smoke column, analogous to daytime cumulus or cumulonimbus clouds, until the effected fuels are consumed. All the vegetation is usually destroyed irrespective of its fuel arrangement because the vertical motion of the fire is easily transferred from ground fuels into the uppermost vegetal canopy. Along steep slopes, fires also spread in "runs," (a long narrow path of heavily burned vegetation oftentimes crossing many vegetation types) which result from the accelerated upslope motion of the fire front due to orographic channeling of superheated air. The complexity of topography also has an influence on fire behavior (Countryman 1964). Vegetation on broad, smooth slopes tends to burn off more completely than slopes containing watercourses, ridgelines and cliffs which

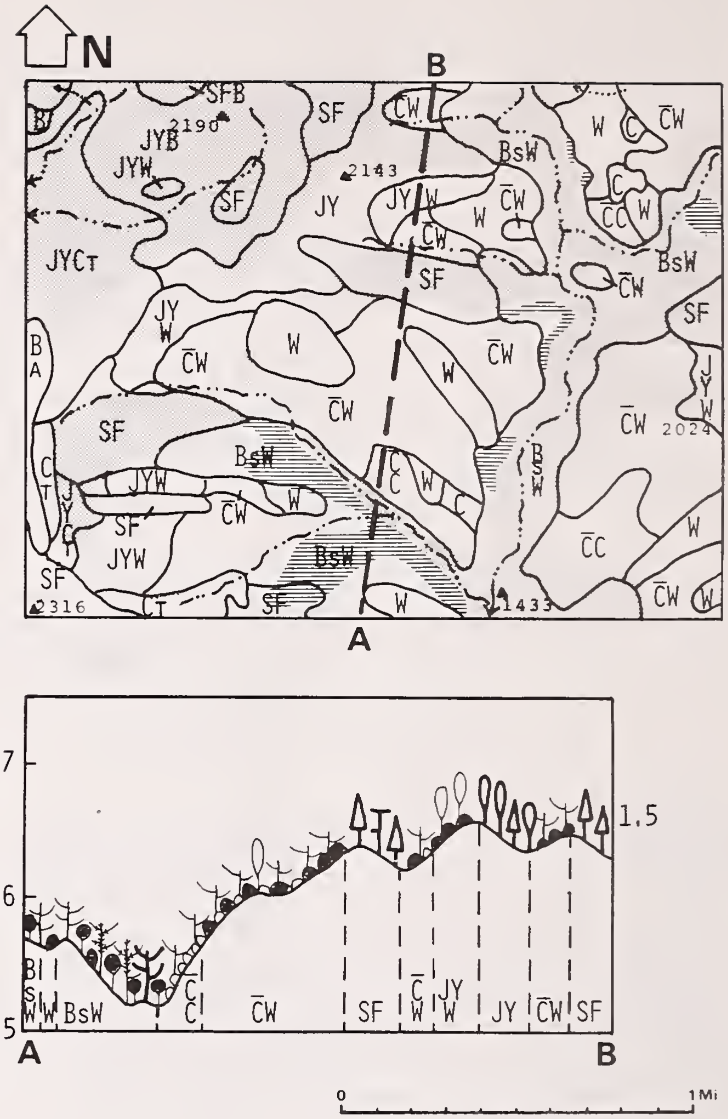

Figure 2--Fire map and profile of surviving (grey tone), killed (white) and sprouting (line tone) conifers: Bear Canyon. Surviving forests on profile shown in thick linework.

interrupt the forward momentum of a fire. As evidence, the mortality of conifer vegetation is greater with increasing slope class with the exception of slopes greater than 30 degrees (greater than the angle of repose).

In spite of these complexities in the fire mosaic, a broad overview of burning summarized in table 2 indicates that big cone Douglas-fir, Coulter pine, and western conifer forests experience different rates of survival. Furthermore, these trends are explainable in terms of their physiognomy and the vertical transfer of fire to the conifer overstory from combusting of shrub and woodland understory.

Coulter pine sustained the heaviest damage as 86% of stands were killed in the five fires examined. The fate of this species is

Table 2--Survival Rate of Conifer Forests in Five Fires
(percent area)

					Slope Class (degrees)				
Type	Total Area [1]	Entire Stand	North	South	0-9	10-19	20-29	30-39	40
$\bar{C}$C	10.2	11	13	10	-	13	14	6	0
$\bar{C}$W	17.0	10	14	9	-	33	8	9	0
$\bar{C}$B	1.0	70	-	70	-	57	100	-	-
All $\bar{C}$	28.2	14	14	12	-	25	13	8	0
BsW	101.0	59	59	60	-	37	39	63	90
BsW sprout [2]	86.8	78	80	76					
JY	10.3	83	91	73	-	100	79	81	89
JYB	14.6	75	83	64	80	73	63	67	-
JYW	18.9	31	41	24	-	30	18	29	62
JYCl	3.5	72	80	70	-	-	-	53	85
JY (SF) Ct	15.0	67	78	61	100	71	57	57	-
SF	14.3	72	72	50	100	100	82	59	100
All JY, SF	76.6	60	76	49	84	78	54	49	75

[1] In hundreds of acres
[2] Sample for two fires only

obviously tied up with the combustion of the chaparral understory. The brush usually burns "clean" because of the horizontal and vertical contiguity of shrubs and the intricate network of fine stems and tiny leaves with a large surface to volume ratio (Countryman and Philpot 1970). Moreover, the advantage of Coulter pine's height is offset by the openness of most stands. Lacking shade stress, the tree prunes poorly with crowns extending downward to the shrub understory, virtually insuring their ignition. The extent of Coulter pine mortality is indicated in figure 2 where a majority of trees on south facing slopes of Bear canyon, underlain by chamise chaparral and canyon oak shrub, were immolated.

Under favorable topographic and physiognomic circumstances, a few stands survived these conflagrations, usually on gentle slopes, in association with oak woodlands. In contrast, 59% of big cone Douglas-fir forests had directly survived the same fires. Its success seems to be related to its general sympatry with canyon oak which as a result of its tree sized physiognomy seems to act as a buffer against chaparral fires.

Analysis of color infrared imagery suggests that fires spreading from chaparral usually incinerated the outermost fringe of stands. With further progress into the grove, the pattern of total combustion graded into a hot surface fire which only scorches the oaks as the distance between the tree canopy and ground fuels increases. Burning in the grove interior consisted of surface fires which were only intermittently hot enough to scorch the oaks. Big cone Douglas-fir individuals were generally undamaged except for the formation of fire scars. The mortality rate of this species also tended to decrease with increasing elevation where only a patchwork of chaparral stands are capable of only locally intensifying the conflagration.

Aerial photography flown four years after two 1970 fires reveal that many defoliated stands of big cone Douglas-fir had sprouted from epicormic buds in the bark along the main stem and major branches (see Gause, 1966). The sprouting habit was not universal, however, and appears dependent on the severity of the fire. As a rule, most sprouting occurred in stands where trees were merely scorched by the heat of ground fires. Forests which crowned rarely sprouted. Most sprouting stands were contiguous with forest which directly survived the fire (see figure 2).

The areal extent of fire damage fatal to western conifer forests amounted to a relatively low 40% of the total stand. Vertical stratification of damage observed in color infrared aerial photography reveal that fires spread largely on ground fuels and was rarely carried as a crown fire due to the openness of stands. In steep terrain, fires usually burned

in "runs--oftentimes leaving a mosaic of unburned forest islands, which were typically destructive due to the effects of slope. This is indicated by contrasting rates of deforestation by slope class which ranged from 84% on slopes less than 10 degrees to 51% for slopes between 30 and 39 degrees. On precipitous slopes greater than 40 degrees, conifer survival was a relatively high 75%.

The rate of western conifer forest mortality is also proportional to the biomass of associated shrub and woodland vegetation. Heaviest mortality occurred in stands sympatric with canyon oak (JYW, 31% survival). In contrast, the survival rate of stands associated with timberland chaparral, mountain mahogany scrub, however, was much higher ranging from 67 to 75%. All vegetation types in western conifer forest experienced strong increases in deforestation rate with increasing slope with the exception of stands free of understory or sympatric with black oak.

POST-FIRE REGROWTH

On table 3 is a brief summary of post-fire regrowth of stands destroyed by fire since the 1938 aerial photographic cover (and a few known earlier known fires) according to dominant conifer species and age class. Comparison of transect data with the 1938 vegetation record at the same location indicates that post-fire vegetation is more or less identical with the former stand at the floristic level, although the physiognomy, of course, is drastically different. Stands burned most recently are dominated by

Table 3--Summary of vegetation by age class

Conifer Species	Age Class (Years)	Shrub Biomass	Conif. Freq. Repro. 100 m.	Percent Conifers > 5 m. tall
C̄	0-9	light	2.3	0
	10-9	medium	5.3	8
	30t	heavy	7.4	75
Bs	0-9	light	0	-
	10-19	heavy	0.1	0
	20-29	heavy	0.6	0
	30t	light[1/]	1.1	71
JY,SF	0-9	none	0.1	0
	10-19	light	6.1	*
	20-29	light	8.0	7
	30t	light	8.7	63

1/ Canyon oak shrubs reach tree size after Ca. 50 years.

shrubs, usually in contiguous thickets. Conifers are prominant in stands older than a few decades although this trend is quite variable depending on the species and the physiognomy of associated vegetation.

Early regeneration of big cone Douglas-fir stands is dominated by canyon oak (Quercus chrysolepis) which arose as a shrub due to the sprouting of numerous stems at ground level. (Despite its size, this oak is relatively thin barked and generally suffers fatal cambium damage in the crown and the main trunk). Canyon oak shrubs are admixed with dense stands of mostly Ceanothus integerrimus and C. leucodermis which presumably germinated from seed stored in the soil (Quick 1959). In older stands, canyon oak forms contiguous stands of large shrubs 3 to 8 m tall, having attained tree size in burns older than approximately 50 years. In these, the forest floor was relatively free of brush due to mass senility and mortality of Ceanothus.

Big cone Douglas-fir reproduction in deforested stands is practically non-existent. No offspring was found in stands less than 19 years old. A few seedlings and saplings were transected in remaining stands ranging in age up to 55 years. The reasons for this trend are unclear. Long distance seed dispersal by wind may be inefficient because the seed is heavy (Gause 1966). Reproduction was also found to be the best in shade provided by canyon oak (Littrell and McDonald 1976; Gause 1966), a condition dependent on the time required for their maturation. Comparison of stands of different age class suggests that sapling growth is suppressed by shade stress until the trees emerge through the oak canopy. Analysis of aerial photography indicates that much emergence requires about 50 years.

Vegetal regrowth in recently burned Coulter pine stands is also dominated by sprouting chaparral and woodland species, mostly in Arctostaphylos, Adenostoma, and Quercus--resembling understory of mature stands--plus a small quantity of Ceanothus leucodermis, C. integerrimus, and C. greggii which established as seedlings. The latter species generally died of senility after 25 to 40 years as most older stands contained numerous carcuses. The chaparral is contiguous in stands older than 10 years, the biomass adequate to support an intense fire after about 20 years.

Most reproduction of Coulter pine occurred within a year of a fire, usually in abundance. Field observations of young stands suggest the seed was diseminated from cones persistent on nearby deceased adults rather than by long distance dispersal, in a fashion similar to knobcone pine (Pinus attenuata; Vogl 1973).

Coulter pine, of course, is not a true closed cone pine. The cones, however, require two years to mature and normally open during mid-winter (Critchfield, pers comm.) well after the fire season. Consequently, they probably opened and released seed in response to the fires. The trees grow vigorously from the start. Seedlings are coarse, containing many cotylgens to insure deep early rooting and are remarkably drought tolerant (Wright 1966a; 1966). In transect data, trees average 0.3 m tall after 4 years, 2-5 m after 20 years, and 10-15 m after 45 years. Cones with viable seed were produced as early as 10 years age.

Western conifer forest stands destroyed by fire underwent brush invation primarily as the result of mass germination of shrub seedlings from seed stored in the soil, similar to disturbed forests in the Sierra Nevada (Quick 1959). Dominant species include Ceanothus integerrimus, C. cordulatus, C. greggii var. vestitus, and Arctostaphylos patula. Species, capable of long distance seed dispersal, also invaded these stands including Artemisia tridentata, Chrysothamnus nauseosis and Cercocarpus ledifolius. The dominant sprouting species, Quercus chrysolepis, Q. kelloggii, and Castanopsis sempervirons, represented a small portion of the total cover.

Total shrub cover is greater than understory present in pre-burn 1938 photography, but is rarely contiguous. Shrub growth is initially slow due to the prominence of seeding species which, unlike sprouters, have to develop their own root systems. Moreover, at maturity (20 to 30 years) shrub biomass is rarely half the value of chamise chaparral. Evidences in transects and aerial photography suggest that montane chaparral tends to open up after 30 to 50 years due to senility deaths of primarily Ceanothus and Artemisia tridentata.

Conifer reproduction was similar for all species. Seed was apparently introduced by wind dispersal from mature stands outside deforestation areas (Fowells 1965). Ecesis had not taken place in most transects of stands younger than 5 years because of poor seed crops and dry winters, although reproduction is usually plentiful in stands older than 10 years. Following the distributional trends of the deceased adults, ponderosa and Jeffrey pine seedlings germinated best on open mineral soils in full sun, while white fir and sugar pine seedlings came up in duff and mineral soil conditions on shady north facing slopes. The growth rates of these species is much slower than Coulter pine; only 8% of trees had reached 15 feet (5.0 m) height in stand 20 to 29 years old. Aerial photo comparison of older stands recovering from deforestation suggests that western conifer forests reach full height growth in about 100 years.

THE FIRE CYCLE, PLANT COMMUNITY STRUCTURE AND GEOGRAPHY

Fires do not burn the biotic landscape indiscriminantly. In spite of apparent random perturbations such as fire storms and local "runs" up steep slopes, the larger view shows that combustion frequency, intensity, and concomitant rates of vegetal destruction is a product of differences in fuel volume, fuel geometry, slope and topography. Plants living together as a "community" are obviously compatible with the fire regime they create. With changes in the physical environment, however, there should be corresponding changes in the vegetation and the burning regime. The combustion of coniferous forests described here is found to be complex as one type is normally destroyed by fire (Coulter Pine) while the others directly survive them (Big cone Douglas-fir, western conifer forest). In an analysis of 36 years of fire history since 1938, it appears that each is "adapted" to fire, but in different ways.

Coulter pine forests are normally immolated by heavy evergreen schlerophyll vegetation at a frequent interval. It reproduces immediately after fire and growth to cone bearing stage requires only a few decades. Western conifer forests are characterized by less ground fuel and tends to directly escape fire. Regeneration to maturity is slower (ca. 100 years) and dominant species rarely reach cone bearing stage before 50 years. Brush invasion, however, is partly temporary due to the predominance of short-lived species which replicate by seed storage. Unlike chamise chaparral, therefore, brush fuel loading is not accumulative. Big cone Douglas-fir forests also directly survive fire because of protection afforded by relatively non-flammable canyon oaks. It reproduces poorly and stands appear to be maintained by a combination of incremental reproduction and post-fire crown sprouting. In case of severe fire, canyon oak is converted into a more flammable shrub which could potentially effect accumulative damage to big cone Douglas-fir overstory with repeated fire. The success of this conifer, therefore, seems dependent on tree-sized canyon oak escaping fire.

The geography of these conifer forests are believed to reflect spatial changes in the long run of the fire regime described here. It follows that in areas outside their distribution, the fire regime will not reconcile with their life cycles. In this regard, on their distribution in the eastern Transverse ranges are offered.

Western conifer forest species and big cone

Douglas-fir are not sympatric with chamise chaparral because the time required for their maturation from seed is greater than the interval of lethal fire events caused by the brush (20-50 years). The distribution of western conifer forests are limited to areas containing low fuel volume evergreen schlerophyllous vegetation (timberland chaparral, mountain mahogany scrub, great basin sage scrub, open canyon oak scrub) where the frequency of fire events fatal to them is low. The lower elevational limit of western conifer forest is inversely proportional to slope; large stands exist on gentle surfaces at quite low elevations (1300 m) where shrub understory continues to be limited and the probability of crown fires through "runs" is low. Big cone Douglas-fir forests extend to high elevations on steep slopes (2300 m) in areas of heavy canyon oak understory. At rare intervals the oak stands immolate conifer overstory, selecting for sprouting big cone Douglas-fir over western conifer forest species. This becomes less probable toward higher elevations because canyon oak drops out. Similarly, Coulter pine forests are also found at high elevations (2200 m) primarily on steep slopes covered by heavy brush which insure a high frequency of crown fires.

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LIFE HISTORY ATTRIBUTES OF PLANTS AND THE FIRE CYCLE: A CASE STUDY IN CHAPARRAL DOMINATED BY CUPRESSUS FORBESII[1/]

Paul H. Zedler[2/]

Abstract: Observations were made and population data were collected on recent burns in San Diego County, California to observe the response of chaparral shrub species to fire. These studies concentrated on Cupressus forbesii and its associated species. It is apparent that there are diverse ways of adapting to and surviving fire, as evidenced by a qualitative description of life history attributes of the species studied. An understanding of the life histories of the constituent species is important to predicting the response of chaparral to management, and necessary to avoid the possibility of irreversible changes. The drastic decline of Cupressus on several sites apparently resulting from increased fire frequency is evidence that dramatic changes in population sizes are possible.

Key words: Cupressus forbesii, chaparral, fire ecology, fire adaptations.

INTRODUCTION

An ideal management program for a natural ecosystem would be to move the ecosystem from any existing state to any other desired state in a series of precisely defined manipulations. In reality, we recognize that management always risks bringing about unwanted changes, or worse, bringing about changes which are irreversible. A management approach which preserves the ability of the ecosystem to return to a variety of states is thus to be preferred. Holling (1973) has termed this ability of ecosystems to be disturbed and still retain the basic components and relations "resilience."

In natural or semi-natural landscapes the need to preserve resilience requires that attention be given not only to gross structural and functional features such as total biomass, primary productivity, forage production, and the like, but also to the abundance, distribution, and future prospects of the constituent species. At the extreme, there is the risk of species extinction, which is the most obvious and final of the ways in which resilience can be altered. Much more likely is the local extinction of populations which may be difficult to reverse within practical constraints.

Obviously, a complete understanding of the consequences of alternative management strategies requires consideration of all aspects of ecosystem function. To be able to predict the fate of species under alternative management practices, it is clear that more will be needed than nutrient cycling and energy flow studies at the ecosystem level. There must also be studies of the population-level responses of the individual species. Such studies must include an emphasis on the major demographic properties, such as seed production, dispersal, vegetative and seed reproduction, germination ecology, and survivorship. Studies like these fall into the area of ecology recently dignified with the title of "plant demography." In plant demographic studies, the emphasis is on the life table, or its equivalent, and its use to make predictions about the behavior of populations under variable circumstances. Such studies are few in number for plants of any kind, and very sparse for long-lived woody plants.

It will be my purpose to try to demonstrate

1/ Presented at the Symposium on Environmental Consequences of Fire and Fuel Management in Mediterranean Ecosystems, Palo Alto, Calif. Aug. 1-5, 1977.

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that such information is essential for intelligent management of Mediterranean ecosystems. I will try to do this with qualitative data on a number of important chaparral shrubs of San Diego County, and with a limited amount of quantitative data on the Tecate cypress, _Cupressus forbesii_.

THE CHAPARRAL FIRE CYCLE

Since I wish to discuss the interaction between the fire cycle and shrub life history, it is necessary to define the terms that will be used to describe major stages in the fire cycle. For the present purposes, it is sufficient to recognize five stages: the fire itself, the early post-fire years, the later post-fire years, closed conditions, and senescence. These stages may be briefly characterized as follows:

Fire (F)--The actual fire, which typically kills all above ground living material and (directly or indirectly) much of the below ground biomass as well. While ground fires which do not burn through the crowns and do not kill all of the individuals may be possible, they are so rare as to be of little significance.

Early Post-Fire Years (EPF)--The first year or two of recovery after fire, during which nutrient and moisture conditions are most favorable, and in which a large proportion of the habitat is available for germination and growth.

Post-Fire Years (PF)--The next few years (c. 2-10 after fire) during which canopies of most plants do not touch, but in which biomass recovery is sufficient that resource abundance is less, and the habitat much less favorable for germination and establishment.

Closed Condition (C)--The time characterized by a more-or-less continuous canopy, at least some build-up of litter, and near maximum exploitation of rooting space.

Senescence (S)--(25 to 100 or more years after fire). The stage of development where the death of large dominant individuals leaves large openings and presumably, therefore, resource use is less intense. The age at which chaparral begins senesce seems to be highly variable. While some stands apparently disintegrate at 30 to 40 years after fire (Hanes 1971), others will be uniformly vigorous at an age of 100 years.

CHAPARRAL SHRUB LIFE HISTORIES

The current view sees plant life histories as the end product of evolution which optimizes the trade-off between the survival of the individual and the production of offspring (Stearns 1976). In a region subject to recurrent fires, it is clear that the adjustment of individual survival and the production of propagules to an optimal balance must accommodate the effects of fire. As is well known, this has led to two major life history types in the chaparral, the so-called "obligate seeders." and the "sprouters." In the first case individual survival has evidently been sacrificed to increase the numbers of seedlings that can be established during the brief favorable period after fire. In the latter case, individual survival is high, but often apparently at the expense of seedling establishment (Keeley and Zedler 1977).

This contrast in life histories is striking, and it is obvious that the pattern of fires could have profoundly different effects on the two types of species. But an important point that I wish to make is that there are other types of life histories in the chaparral, and that even within the sprouter and obligate seeder categories there is a substantial diversity of life histories. Though the contrasts to be found in more detailed analysis of the life histories are not so striking as the seeder-sprouter comparison, they would seem nonetheless to be great enough to be of concern in chaparral management where it is important to predict the long and short run changes likely to result from particular programs.

In table 1, certain life history traits of selected chaparral species are listed. To interpret the table, the life history attributes considered are defined:

Post-fire sprouting--This is the ability to be killed to the ground and recover by the production of new shoots from the base. Nearly any shrub will sprout to some degree if the fire is light enough, but as has been well-documented in California (e.g. Hanes 1971), there are some species which almost never sprout under typical fire conditions.

Seedling establishment from stored seed--This refers to the ability to produce and disperse seeds in such a way that they will germinate primarily in the first year after fire. Species which are able to do this may also be able to produce seeds that will germinate at other times, but there is a tendency for shrubs which establish abundant seeds after fire to establish few or no seeds at other times.

Table 1--Life history attributes of shrub species found in or adjacent to stands of <u>Cupressus forbesii</u> in southern San Diego County, California. Nomenclature follows Munz (1974).

	Sprouts after fire	Seedling establishment from stored seed	Seedling establishment from post fire seed	Vegetative spread during post fire years	Seedling establishment in closed conditions	Continuous seed production to next fire (see text)	Steady-state structure	Primary period for population expansion
I - Sprouters								
I-A								
Xylococcus bicolor	+!	-			+?	+		C?
Cercocarpus minutiflorus	+!			-?	+?	+	±	C?
Quercus dumosa	+!			-?	+	+!		C
Chamaebatia australis	+	-		+	?	±	+	?
Heteromeles arbutifolia	+!				+?	+		C?
I-B								
Arctostaphylos glandulosa	+!	±				+		EPF
Adenostoma fasciculatum	+	+!			-	±		EPF
Rhus laurina	+!	+				±	+?	EPF
Rhus ovata	+!	+				+		EPF
Romneya trichocalyx	+	+	?	+?	?	?	+	EPF,PF?
Haplopappus squarrosus	+		+	+		-	+	PF
II - Obligate Seeders								
II-A								
Artemisia californica		+			±	-		EPF,S?
Salvia mellifera		+			±	-		EPF,S
Salvia apiana	±	+			±?	?		EPF,S?
II-B								
Ceanothus greggii		+!				+		EPF
Ceanothus tomentosus		+!				+		EPF
Cupressus forbesii		+!				+!		EPF

Seedling establishment from early post-fire seed--This refers to the ability to establish seedlings from seeds which are produced by seedlings or resprouts in the first few years after fire. None of the dominant shrubs of the chaparral seem to do this.

Vegetative spread during fire-free period--This refers to the ability to establish new individuals by vegetative spread at times other than resprouting after fire.

Seedling establishment in closed conditions--This is the capacity to establish seedlings at times other than the short period immediately after fires. To do this they must be able to reproduce beneath their own or other species' canopies, or in small openings in older chaparral that are not the result of fire.

Continuous seed production from time of first flowering to the next fire--Species with this property typically grow into the canopy, and once there, remain vigorous enough to produce seed continuously. The intent of defining this feature is to distinguish between those species that flourish for a period of years and then decline to virtual absence, from those species competitive enough to maintain or increase their position relative to other species. Species with this trait have a high probability of well-established individuals surviving to the next fire.

Steady-state shrub structure--Shrubs of humid regions often persist indefinitely beneath forest canopies by the continual production of new shoots to replace senescing old ones, and thus may be said to be capable of having a steady-state structure. Many chaparral shrubs produce few or no sprouts from the base, except for the first few years after fire. This means that growth in these shrubs is a process of fire-induced sprouting followed by thinning in which stems may die, but no new ones are produced from the base to replace them.

Table 1 lists most of the important species of shrubs encountered in my study of Tecate cypress in southern San Diego County, California. The information on the shrubs applies to the species as they behave in San Diego County. In at least one instance (sprouting in Salvia apiana), the behavior of the species in this area is different from that in the rest of the state. Other differences in other species may well exist.

In the table, the presence of a feature as common and well-developed is indicated by a plus sign, the absence of a feature by a blank. Intermediate degrees of expression are indicated as follows: a plus followed by an exclamation point indicates that the trait is strongly present; a plus and minus indicates that the trait is less common or less strongly expressed; and a minus sign that the trait is present but is not common or not well expressed. A question mark after a symbol indicates substantial doubt over the proper classification, but the reader is cautioned that the entire table should be considered preliminary. The final column indicates the stage in the fire cycle when most new individuals are established. Individual, as described here, includes the genet (Harper and White 1974) as well as ramets that are distinct enough from the parent to constitute significant invasion of new habitat.

In the table, the species have been grouped into broad categories of life history type. The traditional separation between the sprouters and obligate seeders is very clear. Five of the species never sprout after fire, except very occasionally when they occur at the margins of a burn. Ten of the species sprout, most of them vigorously enough that their pre-burn leaf area, if not their pre-burn biomass is quickly recovered.

But within each of these broad categories there are differences in life history that could be of considerable significance to their long-run response to fire manipulation. In the non-sprouting group there are those species (group II-B) which have apparently no capacity whatever to germinate except after fire, unless there is severe unnatural disruption of the vegetation, as when an area is bulldozed. In contrast, the two Salvia species and especially Artemisia have the ability to establish seedlings in closed conditions and in adjacent open areas without massive disruption of the soil. Significantly, all three of these species are most successful in the more open vegetation on less favorable sites, being most abundant toward the coast and, in the case of Salvia apiana, again on the desert edge. It seems likely that conditions which favor the spread to group II-A will not probably be equally favorable to group II-B.

Many of the species in these two groups are relatively short-lived, and conspicuously subject to decline in older stands of chaparral (Biswell 1974). This is especially true for species that would be classed in group II-A, and in general for drought-deciduous species. Certain sclerophyllous evergreens that belong to group II-B also seem to develop early and then lose vigor (e.g. Ceanothus oliganthus), but others, like Arctostaphylos otayensis

and Cupressus forbesii, can survive in a vigorous condition to an age of 90 years.

In the sprouter categories (I-A and I-B) there are also contrasts, and sufficient variability that placing them in discrete groups is not entirely satisfactory. However, there is a distinction between species that exploit the early post-fire years by establishing numerous seedlings, and those that seem able to do so only to a very limited extent. This essentially is the same distinction made by Naveh (1975) in his discussion of the fire-related adaptations of Mediterranean plants. In group I-A, the species sprout vigorously after fire, but establish few or no seedlings, despite considerable fruit production between fires. In some cases, as with Pickeringia montana over the greater part of its range, this failure to establish seeds may be due to sterility or low seed viability; but it is doubtful that this can explain the behavior of the five species in group I-A. More likely, the seeds of some of the species simply are not well adapted to post-fire germination. This lack of adaptation may be either physiological, or due to an inability to survive in the soil to the next fire.

Since conditions for the expansion of population size by seed seem to be most favorable after fire, it is surprising that these species have not evolved the ability to exploit post-fire conditions. There are at least three possible explanations for this situation. These are not mutually exclusive. First, it may be that successful post-fire germination is highly variable from fire to fire, and that therefore establishment in some of these species can be observed only rarely. Such variation could arise because of mast years, predators, climatic variation, or a complicated interaction of all three. Second, it may be that evolutionary constraints make it impossible for certain species to evolve the proper combination of fruiting phenology, seed behavior, predator protection, dispersal, and reproductive effort that are required to successfully exploit the post-fire situation. Such constraints may be only temporary for species recently incorporated into the chaparral, or they may be virtually permanent. Lastly, it is of course possible that the ability to exploit post-fire conditions may not be so uniformly advantageous as it seems.

The case of Quercus dumosa (scrub oak) seems to be adequately covered in the second explanation. I have never observed seedlings of this species in recent burns, and seedlings in other conditions are rare, despite reasonably consistent production of viable acorns. But, although rare, seedlings do occur. I have seen most of them in older stands, generally ones with a well-developed litter layer. The greatest abundance I have noted was in a 90 year old stand with patches of deep litter. The seedlings were scattered in groups, a pattern surely resulting from caching by small mammals.

It is fairly clear that the acorn is not well suited either to long-term survival in the soil, or to storage on the tree in fire-resistant form. While in theory one supposes the acorn could be altered to possess these properties, it is not surprising that such an ancient and successful structure should be conservative. Most likely the variation is simply not present for evolution to act on. Scrub oak thus represents a xeric derivative from some mesic species or species complex whose vegetative vigor and longevity compensate for what seems to be a less than optimal rate of establishment from seed.

The behavior of Xylococcus bicolor is less easily explained. This species is a vigorous sprouter, and seems almost immune from death by fire. However, seedlings are rare. Detailed examination of more than 450 square meters of belt transects in burns in which Xylococcus was abundantly present on or adjacent to the sampled area revealed only one half-dead seedling. Another vigorous seedling was found off the transect. No seedlings of Xylococcus have been found in three other burns in which resprouting Xylococcus was present. Considering the present abundance and vigorous seed production of Xylococcus, this lack of seedlings is puzzling. Unlike Quercus dumosa, Xylococcus does not seem to be able to exploit closed conditions. It may be that even the small number of seedlings that are present in burns are sufficient to maintain the populations, but then the reproductive success of the Xylococcus seems very low.

It may also be that the present conditions are not representative of those that led to the establishment of the present stands. It is possible, for example, that seed predators are more abundant or effective than they have been in past times, or that longer intervals between fires are necessary for the accumulation of sufficient viable seed at the proper depth for successful establishment.

The second group (I-B) differs in that all members can both sprout and establish seedlings. One would expect this to be the most successful life history, and it is not surprising that Adenostoma fasciculatum, the most abundant plant of the California chaparral, belongs to this group. Note also that

Adenostoma, in at least some years and in some places, can have seedlings germinate without fire and in closed conditions. Included in this group is Haplopappus squarrosus, a sub-shrub in the Compositae, which I have listed here mainly to show that at least one shrubby plant is able to establish new individuals from seed produced after the fire. I have noted this in two burns some distance apart. In one of these burns, a north facing slope had many thousands of seedlings on it resulting from seed produced by the resprouted stems. This establishment took place a little over a year after the fire.

It will require much more than this crude table to predict which of these species may be expected to increase or decrease in response to different types of manipulation. But with respect to fire, even this limited presentation makes it clear that species will respond quite differently. At the first level, there are species whose life cycle is dependent upon fire to a degree which must make them highly sensitive to large scale shifts in fire pattern. This group of "fire-sensitive" species would certainly include all of the species except sub-group I-A. Within the fire sensitive group there remain significant differences. Sub-group II-B should be very sensitive to both increasing and decreasing fire frequency, since species in this group cannot establish effectively without fire, but at the same time must not be burned before sufficient seed for the next generation has been produced. Sub-group II-A, however, while sensitive in a negative way to increasing fire frequency, might conceivably benefit from decreasing fire frequency because of the ability of these species to persist, and possibly spread under conditions of senescence.

Group I-A might be called fire insensitive, not because fire has no effect, but because there seems to be no direct dependence upon fire. Established plants are virtually certain to survive fire, and seedling establishment apparently takes place at times other than after fire. They are also long-lived, so that whether fire frequency is high or low, the probability of dramatic population reduction should be minimal. In the long run, the indirect effects can be significant, if not because of fire effects on site conditions, then certainly because the greater or lesser success of the fire-sensitive species will ultimately be an influence.

I believe that this qualitative view of shrub life histories suffices to show that manipulation of chaparral, and specifically manipulation of the frequency of fire could be a major determinant of the relative abundance of species. It is less clear that there is any danger of destroying the resilience of the chaparral. If a series of manipulations can be readily reversed, there is little reason to be concerned about short-range changes in relative abundance.

In the following section, I will briefly discuss some of the preliminary data derived from a study of Cupressus forbesii, especially the recovery of this species from a series of recent burns. On the basis of data collected so far, it seems likely that this species is headed for extinction under the present fire regime. If this belief is correct, it is evidence that at least some chaparral systems are not resilient in the face of disruption of the presumed normal pattern of fires.

A CASE HISTORY--CUPRESSUS FORBESII

Cupressus forbesii (Tecate cypress) is a closed-cone conifer, which retains closed cones on the branches that disperse seed only after fire, and nearly always only after death of the parent tree. This behavior may be thought of as simply an extreme case of the obligate seeder life history (group II-B). This species, possibly widespread in coastal California in the Neocene (Axelrod 1967), is now restricted to four sites in southern California, and a scattering of locations in northern Baja California, Mexico. Where it occurs, it is a dominant; being remarkably hardy and long-lived. As stands increase in age after fire, the cypress gradually surpasses most of its shrubby competitors, and tends to occur in nearly pure stands or a scattering of discrete clumps.

Cone production begins at an age of about ten years and accelerates so that by 25 to 30 years a few trees in favorable locations may have as many as one thousand cones, each with about 30 viable seeds. However, maximum cone production seems not to be achieved until about 50 years or even later. For populations to be maintained, the interval between fire must be long enough to permit the trees to grow large enough to produce substantial numbers of cones.

I have studied stands of Tecate cypress on Tecate and Otay Mountains in southern San Diego County where there have been a number of fires in the past forty years, including fires in 1975 on Tecate Mountain, and 1976 and 1977 on Otay Mountain. The 1975 fire on Tecate burned an area which I had previously sampled in 1972. This area, and others, were sampled in 1976. At both times, estimates of the number of seeds available to establish the new

generation could be obtained by counting the cones remaining on the burned trees. A low estimate of pre-fire density could be obtained by counting the number of stems which survived the fire.

I intend to publish elsewhere a fuller discussion of all of the data, and will present here density data from only two of the stands sampled. These two stands are both on Tecate Mountain and occur adjacent to one another on a steep, generally north-facing slope. Both stands were burned in 1880, 1944, and again in 1975. One of them, the Smuggler's Canyon stand, also burned in 1965; while the second stand, Bigrock, escaped this fire, which was brought under control by the California Division of Forestry.

In the Smuggler's Canyon stand, the trees which were killed by the 1965 fire remained, and still retained their cones, so that an estimate of the numbers of trees and the numbers of cones on them at the time of the 1965 fire could be obtained. This, with the 1976 data, allowed the following estimates of density to be calculated. The figures in parentheses are estimates based on extrapolation from other stands of similar age, but are conservative estimates of density:

Smuggler's Canyon

Year	Length of Time Since Last Fire (Years)	Cypress Trees/m^2
1945	0.5	($\sim$1.5)
1965	11	> 1.4
1966	0.5	(0.04)
1972	7	0.03
1976	1	0.02
1985	10	($\sim$0.015?)

These figures confirm quantitatively what is readily apparent on inspection of the stand. On this site, Tecate cypress has been reduced, in less than 35 years, from a dominant to a minor component of the vegetation.

The adjacent Bigrock stand has also suffered a decline, but because it has experienced one less fire, the reduction is not nearly so drastic. As above, the figures in parentheses are estimates. This stand was denser than the Smuggler's Canyon stand, and was also much older at the time of the 1975 burn, but there was still a very marked loss of individuals. The present seedling crop is now at a density very much higher than the probable density of a 63 year old stand, and much below the density of the stand that burned:

Bigrock Stand

Year	Length of Time Since Last Fire (Years)	Cypress Trees/m^2
1943	63	($\sim$1.0)
1945	0.5	(>14.0)
1972	28	8.9
1976	1	1.4

A similar pattern seems to be present in a 1976 burn in a 34 year old cypress stand on Otay Mountain, about 15 km west of Tecate Mountain. Preliminary data indicate that the present seedling density is about 0.44 per square meter, compared to a pre-burn cypress density of 0.8.

While it is probably true that the Tecate cypress has undergone considerable variation in abundance in past times, the present precipitous decline in recent fires cannot be accounted for by invoking changing climate, pest problems, or disease. The most economical hypothesis is simply that the cypress cannot reestablish at maximum density unless enough time has elapsed between fires to permit the trees to grow past their competitors into a position of dominance and maximize their production of cones.

If this is true, then it must be that fire frequency is higher in this area at present than it has been in the past. Since all three of the fires which have burned in the cypress in the last three years were started by humans, it is likely that the fire frequency under natural conditions would have been lower. The fact that cypress stands 28 and 34 years old did not reestablish vigorously enough to maintain their densities suggests that the natural period between fires was much longer than 40 years in the areas where cypress grows, and therefore longer than the commonly cited "25-year" fire cycle. Burning as frequently as every 25 years would probably lead to the extinction of cypress. If it would not be complete extinction, it would at least be local extinction, and an elimination of the species as a significant element of the chaparral in areas where it now predominates.

It is also important that there is probably no manipulation of the cypress stands, short of artificial planting, that will allow the stands to be expanded as rapidly as they have declined. This is because cypress seeds have very limited dispersal. They tend to fall directly below the tree, and since the stands are mostly on steep slopes, dispersal is mostly downhill. Not surprisingly, it is upslope areas that seem to be suffering the most drastic decline in numbers.

Taking all the evidence together, the case of <u>Cupressus forbesii</u> seems to be one in which human activities have led to a diminution of ecosystem resilience by local extinction of a dominant species. So far as can be determined, this is a direct result of the failure of reproduction arising from a change in the pattern of fire, and not the result of changes in site conditions. It is the kind of ecosystem disruption that should be predictable from a knowledge of life history attributes and the demography of species.

IMPLICATIONS FOR MANAGEMENT

It may be that the Tecate cypress represents a unique situation, and that therefore the process of local extinction which seems to be taking place may be no more than a footnote in chaparral natural history. I believe, however, that although the cypress case may be extreme, it illustrates the fact that it is unwise to assume that species well adapted to fire must necessarily have populations that are always robust in recovering from fires.

In the case of cypress, the fires that are decimating the populations are of human origin, but are accidental or criminal. However, controlled burns to reduce fuel densities to desirable levels from the standpoint of property protection, would probably lead to the local extinction of cypress. If a single fire-sensitive species can be brought to the edge of extinction, it is not unreasonable to suppose that other species with very similar life histories might also be similarly affected. In fact, all of the fire-sensitive species should feel some effect. These effects may not always be beneficial to management goals, and may be difficult to reverse. The frequency of fire is a major determinant of community composition, and should be selected with great care and a clear understanding of its consequences, an understanding which can only be complete if there is knowledge of the life histories of the species involved.

There is another further aspect of practical importance in the cypress example. If fire frequency was lower under primeval conditions, it may be true that the shorter fire cycle, associated as it must inevitably be with some loss of soil, might degrade sites at an unacceptable rate, and lead to irreversible changes in species composition, productivity, or cover because of site degradation. If the main objective of chaparral management is to get rid of brush, this may be desirable, but it would be best to approach this end knowingly.

ACKNOWLEDGEMENTS

This study was supported in part by NSF grant DEB 76-19742 and by a U. S. Air Force Summer Faculty Fellowship.

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FIRE MANAGEMENT IN THE YOSEMITE MIXED-CONIFER ECOSYSTEM [1/]

Jan W. van Wagtendonk [2/]

Abstract: Fire has always played a role in the ecosystems of Yosemite National Park. Management of the Park under a policy of protecting the forests from fire has led to unnaturally high flammable conditions. The present fire management program at Yosemite recognizes the dynamic role of fire. Naturally occurring fires are allowed to run their course in 63 percent of the Park and prescribed fire is used to return the remaining portion to its original condition. Burning prescriptions have been derived to meet management objectives.

Key words: fire management; prescribed fires; Yosemite National Park.

INTRODUCTION

As in other areas with Mediterranean climates, fire has had a pervasive influence on the ecosystems of Yosemite National Park. Descriptions of the forests by early explorers spoke of open columns of trees and the general lack of undergrowth. Such conditions were attributed to low intensity periodic fires set by lightning or by Indians.

With the coming of European man, however, these conditions began to change. Settlement of Yosemite Valley began soon after its discovery in 1851. This practically eliminated Indian burning as their lands became occupied. When the Valley and the Mariposa Grove of Giant Sequoia (Sequoiadendron giganteum (Lindl.) Bucholz) were set aside in 1864 as a state reserve, an era of protection began. The 1890 act establishing Yosemite National Park required that regulations be made "for the preservation from injury of all timber, mineral deposits, natural curiosities, or wonders...and their retention in their natural condition." Fires were considered a threat to the Park's resources and were extinguished as soon as possible.

Administration of the Park by the U.S. Army in the early 1900's and finally by the newly established National Park Service in 1916, intensified the efforts to eliminate all fires from the Park. As a result, debris, which had originally been kept at a low level, began to accumulate. Understory trees and brush were able to become established beneath the tall trees in the overstory. Increased fuel accumulations and dense growth made the potential for an extremely severe fire even greater. Over protection of the forest from fire led to conditions which threatened the very existence of the forest.

This situation was recognized by the Special Advisory Board on Wildlife Management for the Secretary of the Interior (Leopold et. al., 1963). The Board recommended that ecosystems be restored as nearly as possible to their pre-European man conditions using as natural a means as possible. The Leopold Report became incorporated into Park Service policy in 1968. That policy now states that fire is recognized as a natural factor in many Park ecosystems, and should be allowed to run its course under prescribed conditions. In addition, in those areas where unnatural fuel accumulations occur, prescribed fires can be used as a management tool to restore natural conditions. Park Service policy has evolved from a philosophy of protecting objects to one of perpetrating natural processes.

[1/] Presented at the Symposium on Environmental Consequences of Fire and Fuel Management in Mediterranean Ecosystems, Palo Alto, California. August 1-5, 1977.

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THE ROLE OF FIRE IN YOSEMITE

Yosemite National Park encompasses a broad range of vegetation types from chaparral stands at 600 meters to alpine fell fields at 4,000 meters. Not only does the vegetation vary within this range, but also the nature of the fuels and the probability of ignition. Consequently, the role of natural fire in these types varies from being a dynamic force in the chaparral and mixed-conifer types to being insignificant in certain alpine types.

In order for fire to be a factor, three conditions must be met. First there must be an ignition source such as lightning or volcanos. Secondly, there must be sufficient fuel to be ignited, and finally, the weather must be favorable for the fire to be spread once ignited.

Lightning is an ever-present phenomenon in Yosemite during the summer months. For the 46-year period from 1931 to 1976, over 1,600 lightning fires were ignited. The average number of fires per year was 36.5 with a range from 1 fire in 1954 to 121 fires in 1967. Of these fires, less than one percent occurred below 1,300 meters in the chaparral zone, 37 percent between 1,300 meters and 2,000 meters in the mixed-conifer zone, 40 percent between 2,000 meters and 2,700 meters in the red fir (Abies magnifica A. Murr.) zone, 20 percent between 2,200 meters and 3,300 meters in the Lodgepole pine (Pinus contorta Dougl.) zone, and the remaining 2 percent above 3,300 meters in the subalpine and alpine zones.

The number of lightning fires, however, only indicates lightning strikes which were able to ignite fires which were subsequently detected. Many strikes did not result in a fire and many others were not detected before they burned out. In the mid-elevations, lightning is an important ignition source. Less lightning fires burn in the chaparral zone because less lightning strikes occur there. On the otherhand, in the sub-alpine and alpine zones, weather and fuel conditions are such that a lightning strike seldom results in a fire.

Although most lightning fires were suppressed prior to 1972, fire size is still a useful indicator of the role fire plays in certain vegetation types. One would assume that large suppressed fires would have been proportionally larger if allowed to burn. Weather and fuel conditions combined with an ignition source produce fires of various sizes. In those areas where fire plays a more important role, fires should be largest. Fire size data show that fires in the mixed-conifer type at about 1,500 meters in elevation are 20 times larger than fires at all elevations. Average fire size at that elevation was slightly more than 40 hectares. When conditions are favorable at other elevations large fires can occur such as a single fire at 2,600 meters which burned 1,600 hectares in 1974. Fires which burn large areas occur on the average of every 15 years and burn during the month of September.

FIRE MANAGEMENT IN YOSEMITE

The National Park Service recognizes the different ways fire behaves in its ecosystems and is managing them in such a manner that fire can play its natural role. Fire management in Yosemite presently falls into three major categories: natural fire management, routine wildland fire control, and prescribed fire management.

Natural Fire Management

In those areas in the Park where natural conditions have been affected least by past fire suppression activities, a natural fire management zone has been established. Within this zone, all naturally occurring fires are allowed to run their course as long as they can be contained within predetermined management units and when burning is consistent with approved management objectives.

Most of the 194,856-hectare zone is located above 2,000 meters although in some areas the zone dips down to nearly 1,100 meters. At the higher elevations the influence of fire has not been as great and biological growing conditions have been less favorable than they are below. The resulting forest has, consequently, deviated little from what are thought to be natural conditions. A naturally-occurring fire in this zone should behave as it would have had there been no intervening years of fire suppression activity.

The natural fire management zone is expanded during the fall and spring to include an additional 53,100 hectares designated as a conditional fire management zone. In this area, fires are allowed to burn after specific weather conditions have been met and until the fire season officially opens.

Since 1972, over 100 fires have been allowed to burn in the natural and conditional fire management zones. These fires are summarized in table 1.

Table 1 -- Natural fires allowed to burn within Yosemite National Park 1972-1976.

Year	Area In Zone Hectares	Number of Fires	Area Burned Hectares
1972	75,679	8	.13
1973	188,445	27	14.20
1974	188,445	22	1687.43
1975	194,856	20	314.54
1976	194,856	35	328.87
TOTAL	-------	112	2345.17

Routine Wildland Fire Control

During the fire season, all fires which are not in the natural fire management zone are extinguished. This area includes 113,239 hectares except when the conditional zone is in effect when it is reduced to 59,522 hectares. These fires are primarily lightning caused although man-caused fires are common near developed areas and along roads.

Fires burning in this zone are usually more intense than fires would have been under natural conditions. The accumulations of debris and increased understory vegetation make unnatural levels of fuel available to these fires. Until the fuel is reduced, fire suppression will continue in this zone.

In addition to controlling routine wildland fires, fire management activities include monitoring natural fires in the Park and suppressing them if they do not further management objectives or if the burning prescriptions are exceeded.

Prescribed Fire Management

Prescribed fire has been used in Yosemite National Park since 1970 in an effort to reduce fuel accumulations and to restore natural conditions. The objective of the program is to return the ecosystems of the Park to the condition they would have been in today had fire suppression activities not taken place.

All areas in the Park not in the natural fire zone are in the prescribed fire zone although the major emphasis has been placed in the mixed-conifer ecosystems. In this ecosystem, ponderosa pine (*Pinus ponderosa* Laws.) and giant sequoia are dependent on frequent low-intensity fires to reduce competition from more shade-tolerant incense-cedar (*Libocedrus decurrens* Endl.) and white fir (*Abies concolor* (Gord & Glend.) Lindl.).

The prescribed fire zone is divided into burn areas which are further divided into burn units. Specific objectives are set for each unit and prescriptions to meet those objectives are specified. These include frequency of burning as well as fuel and weather conditions for burning.

A total of 42 prescribed fires have burned over 2,000 hectares since 1970. Table 2 summarizes these fires.

Table 2 -- Prescribed fires within Yosemite National Park, 1970-1976.

Year	Number of Fires	Area Burned Hectares
1970	8	391.74
1971	8	429.78
1972	1	25.90
1973	2	77.70
1974	3	104.81
1975	7	923.90
1976	13	329.41
TOTAL	42	2283.24

Once an area has been returned to its original condition as closely as possible, the natural fire management zone boundary would be altered to include it. Some areas, of course, would remain in the prescribed fire zone since high values would preclude allowing a natural fire from running its course. Routine wildland fire control would continue in such areas.

BURNING PRESCRIPTIONS

In order to use fire to meet management objectives, burning prescriptions must be derived. Early prescribed burning work in the Park was based on prescriptions written by Schimke and Green (1970). These were later refined by van Wagtendonk (1974) for use in specific lower mixed-conifer fuel types. These prescriptions used the California Wildland Fire Danger Rating System (USFS 1962). Since that time, the national system (Deeming, et. al. 1972) has become universally applied. The prescriptions have been rewritten using the variables in the National Fire Danger Rating System.

Fuel Model G was used as the most representative of the mixed-conifer ecosystem in Yosemite. This model is characterized by dense conifer stands with heavy accumulations of downed tree material and deep litter. In order to expand the prescriptions to the upper mixed-conifer-red fir and giant sequoia types, numerous prescribed fires were monitored for weather and fuel conditions, fire behavior, and fire effects. The resulting refined and expanded prescriptions are included in table 3.

The NFDRS is being revised and will be released to users in early 1978 (Deeming 1976). This revision is expected to remedy certain known deficiencies in the system and to make it more responsive to management needs. The burning prescriptions for Yosemite will subsequently be revised to reflect the changes.

Table 3 -- Burning prescriptions for Yosemite National Park expressed in terms of the National Fire Danger Rating System (Deeming, et. al. 1972) using Fuel Model G.

Prescription Variable	Lower Mixed Conifer 900m-1800m So. Exposure 900m-1700m No. Exposure		Upper Mixed Conifer 1800m-2400m So. Exposure 1700m-2400m No. Exposure	Sequoia Groves 1600m-2000m
	Spring	Fall	Fall	All Year
Wind Speed (MPH)	0 - 10	0 - 10	0 - 10	0 - 10
Air Temperature (^{o}F)	30 - 84	30 - 89	30 - 89	50 - 89
Relative Humidity (%)	25 - 64	25 - 64	25 - 64	20 - 46
1 hr. time lag fuel moisture (%)	5 - 8	5 - 8	4 - 8	3 - 6
10 hr. time lag fuel moisture (%)				
FUEL TYPES:				
Bear Clover	6 - 16	6 - 16		
Needle (pine)	6 - 16	6 - 16		
Meadows	6 - 16	6 - 16		
Incense Cedar	6 - 11	6 - 16		
Needle (Pine, fir)			6 - 10	
Sequoia				6 - 8
Brush (manzanita, ceanothus)	9 - 17	9 - 17	9 - 17	
100 hr. time lag fuel moisture (%)	13 - 25	13 - 18	9 - 16	8 - 14
Fine Fuel Moisture (%)	6 - 12	6 - 10	5 - 9	4 - 6
Ignition Component	16 - 50	21 - 53	23 - 54	50 - 70
Spread Component	1 - 2	1 - 2	1 - 2	1 - 2
Energy Release Component	13 - 32	26 - 39	32 - 49	36 - 52
Burning Index	8 - 15	10 - 16	12 - 18	13 - 16

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PATTERNS OF POST-FIRE SUCCESSION ON THE DONNER RIDGE BURN, SIERRA NEVADA[1]

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and

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Abstract: We examined changes in vegetation and breeding bird populations following fire in the northern Sierra Nevada. Plant post-fire successional stages were 1) Jeffrey pine seedlings, young brush, herbs and grasses, 2) extensive brush with pine saplings, 3) pine-fir forest with fir understory, and 4) a potentially pure white fir forest. The white fir stage actually was not found, probably because of the prevelance of fire. A higher elevation red fir forest was substituted for study. Bird species diversities were about equal in early post-fire and mature forest stages, but diversity was lower during the brush-dominated phase of succession. Many bird species were habitat generalists common to early and late stages.

Key words: fire, secondary succession, species diversity, coniferous forest, avifauna, _Abies concolor_, _Abies magnifica_, _Pinus jeffreyi_.

INTRODUCTION

Wildfire is a powerful force shaping coniferous forests in western North America (Weaver 1974). It follows that an understanding of post-fire succession will facilitate interpretation of many existing communities and allow us to make useful predictive statements about patterns of change in western montane ecosystems.

For the past 15 years we have been studying the Donner Ridge burn in the Sierra Nevada of northern California. This fire occurred in August, 1960, and burned about 16,000 ha, mostly of pine (_Pinus_) and/or fir (_Abies_) forest. We have been especially interested in patterns of conifer regeneration (Bock and Bock 1969, Bock et al, 1976) and changes in breeding bird populations (Bock and Lynch 1970; Bock et al, in press). Birds can be sensitive and valuable indicators of changing community structure because they are highly mobile and because their natural histories are so well known (Grinnell 1928). In this paper we attempt to present an overall picture of post-fire succession in our study area, by summarizing previously published information and presenting new data on vegetation and breeding birds in this part of the Sierra Nevada.

STUDY AREAS

Pilot projects were begun in the summer of 1963 near the Sagehen Creek Field Station of the University of California, 19 km north of Truckee, Nevada Co., Calif., at 1950 m elevation. In 1965, 2 permanent 8.5 ha plots were established, one on the burn and one in adjacent unburned forest. Each plot was divided into 91 subplots 30.5 m on a side. The unburned plot is a mixed coniferous forest (see table 1). All woody vegetation was destroyed on the burned plot except for a few

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mature pines and firs spared by the fire. Today (1977) the burned plot is a mixture of young pines and, especially, various species of brush (table 1).

Data from the unburned plot strongly suggested that in the absence of fire, an unlikely phenomenon, the final post-fire successional stage would be a pure white fir forest. We were unable to locate such a forest near the Sagehen Creek Basin. However, in the summer of 1977 we established a temporary 4.7 ha study area in a mature stand of red fir (Abies magnifica) on Yuba Pass (2043 m elev.) about 25 km north of the permanent study plots.

METHODS

Vegetation composition was determined by running line transects (Kershaw 1964) along established routes on the various study plots. The category "litter or bare ground" was recorded only when nothing else was present at a particular sample point. Line transects were run in 1963 and 1975 on the burned study plot, in 1975 on the mixed forest plot, and in 1977 on the fir plot.

To determine actual densities of trees, total counts were made on a randomly selected 300 m^2 subplot of each major study area. Counts were made in 1965, 67, and 74 on the burn, in 1965 in the mixed forest, and in 1977 in the fir forest (see table 2).

The Williams spot-mapping method was used to census breeding bird populations in the various habitats (Williams 1936). This approach to estimating densities involves the repeated location of breeding birds on a grid, with clusters of observations revealing the presence of nesting pairs. The grid in this case consisted of the 30.5 m by 30.5 m subplots, marked with posts or flags at each corner. Pilot data gathered on the burn in 1963 were from a small (2 ha) temporary plot, and may be only approximations of actual bird density and diversity. Numbers of censuses were as follows: burn (63) - 12; burn (68) - 15; burn (75) -11; mixed forest (75) - 11; fir forest (77) - 9.

RESULTS

Vegetation

Table 1 shows the results of the vegetation transects. Chi-square analyses reveal that every category shown is distributed nonrandomly across the four vegetation types ($p < .05$). Statistics scarcely are necessary because the trends are obvious. We have observed a significant growth of young pine and brush between 1963 and 1975. Projecting forward to the mixed coniferous forest plot, it is apparent 1) that pine will continue to increase in importance on the burn for many years, 2) that brush will decrease, and 3) that fir, virtually absent from the burned plot, will become common. The trend for fir to replace pine is evident on the mixed forest plot; its ultimate dominance (barring a fire) can be seen in the fir forest transect results. Also, brush essentially had disappeared from this final stage.

Table 1 -- Results of vegetation transects. All objects were recorded (including tree canopy) which were intersected by vertical lines at 1 m intervals along transects. Sample sizes: 1963 burn - 300; 1975 burn - 1170; mixed forest - 1170; fir forest - 1007.

Category	Percent of points			
	1963	1975	Mix	Fir
Pinus jeffreyi	0	5.4	23.3	0
P. murrayana	0	1.3	0.6	0
P. lambertiana	0	0	1.7	0
P. monticola	0	0	0	0.5
PINE SUBTOTAL[1/]	0	6.7	25.5	0.5
Abies concolor	0	0.1	46.7	6.3
A. magnifica	0	0	3.0	54.3
FIR SUBTOTAL	0	0.1	49.7	60.6
Arctostaphylos patula	0	3.8	0	0
Ceanothus velutinus	2.5	18.5	2.6	0
C. prostratus	0	17.4	11.8	0
Ribes cereum	0	1.5	0	0.1
Misc. shrubs	0	2.0	2.2	0
SHRUB SUBTOTAL	2.5	43.2	16.6	0.1
Herbs and grasses	16.0	42.1	3.8	3.4
Dead brush, logs, snags	21.0	23.3	6.2	29.2
Litter or bare ground	60.5	20.3	22.2	25.3

[1/] Some pine undoubtedly were present by 1963, but in such low numbers that this small pilot study failed to detect them.

Tree density data are presented in Table 2. Again, each category is distributed nonrandomly among the sample plots ($p < .05$). Table 2 clearly shows the transition from

Table 2 -- Density of trees in the various post-fire successional stages.

Age class[1/]	Trees/ 300 m^2 1965	1967	1974	Mix	Fir
Seedlings					
Pinus	428	325	34	1	2
Abies	29	12	1	682	6942
Saplings					
Pinus	0	64	424	387	0
Abies	0	10	11	1218	2306
Mature					
Pinus	5	5	6	101	0
Abies	4	4	4	89	108

1/ Mature trees $\geq$ 25cm dbh; saplings < 25cm dbh and > 0.5cm diameter or, for pines, > 5 yrs. old; seedlings $\leq$ 0.5cm diameter or, for pines, $\leq$ 5 years old.

pine to fir. Pine seedlings were more abundant in 1965 than at any later stage, suggesting that most pine recruitment occurs soon after a burn (but see Bock et al 1976). The large numbers of fir of all ages in the mixed forest suggest that at some time in the relatively near future fir seedlings should begin to establish themselves on the burn. Mature fir trees spared by the fire have provided a continuous seed source. However, little fir recruitment had occurred through 1974. We found no sign of further fir establishment during a brief visit to the burn in June 1977.

Breeding Bird Populations

We have discussed elsewhere the details of the breeding avifaunas on the burned and mixed forest permanent study plots (Bock and Lynch 1970; Bock et al, in press). Here we wish to consider only the general questions of total density, species diversity, and similarity among the various avifaunas, including for the first time data from the 1963 burn and the red fir forest. Table 3 shows richness, species diversities and densities for 5 successional stages. Table 3 gives results for the actual study plots as well as numbers for a hypothetical complete burn; the latter were calculated by excluding birds dependent upon those few mature trees spared by the fire (see table 2).

Table 3 -- Breeding bird species richness (= number of species), diversity, and density (no./40.5 ha) during various stages of post-fire succession.

Item	1963	1968	1975	Mix	Fir
Richness					
Observed	15	23	20	21	17
Complete burn [1/]	9	19	16		
Diversity (H')[2/]					
Observed	2.59	2.81	2.35	2.42	2.60
Complete burn	2.04	2.68	2.25		
Density					
Observed	152	109	104	102	96
Complete burn	105	95	100		

1/ These hypothetical calculations were made for the burn by excluding species dependent upon mature trees spared by the fire.

2/ $H' = \sum_{i=1}^{s} p_i \log_n p_i$ (see Peet 1974).

Diversity and density were high in 1963. However, a large percentage of the birds present that summer were dependent for nest sites and perhaps some of their food upon mature trees present on the burned study plot. These birds, as well as those species capable of nesting in the burn itself, fed opportunistically in 1963 on insects living in and emerging from standing dead timber. By 1968 the contribution made by species dependent on the mature trees had dropped sharply. Total densities remained very stable through the remaining stages of post-fire succession. Species diversity reached an apparent peak in 1968, dropping markedly by 1975 when the burned plot had become brush-dominated. Table 3 suggests that diversity will increase if the burned plot escapes fire and passes through the mixed conifer to the mature fir forest stage.

Tables 4 and 5 show similarities among total breeding avifaunas and among avifaunas excluding from burned plot results those species requiring fire-spared mature trees. Note that the similarity index used is based not simply on presence or absence of species, but rather upon species' relative abundances (see Beals 1960). Table 6 shows the mean similarity between each successional stage and the remaining 4 community types. Two important findings emerge from this analysis. First, the breeding bird assemblage on the burned plot in 1975 was more distinctive than might have been expected, considering that its intermediate position (among those stages we sampled) should have allowed for a high degree of overlap with other stages. Second, early and late stages were quite similar, even if we exclude from the burned plot those species dependent upon mature trees spared by the fire. In fact, 10 of 20 supposed burn specialists breeding on the burned plot during at least one of our census years also were found on the mixed coniferous and/or fir forest plots.

Table 4 -- Percent similarities[1/] between the breeding avifaunas of the various post-fire successional stages.

Year	1963	1968	1975	Mix	Fir
1963	-	59	35	48	47
1968		-	54	41	42
1975			-	28	33
Mix				-	77

[1/] Computed by $S = \frac{2W}{a+b}$ (see Beals 1960).

Table 5 -- Same as table 4, except species dependent upon mature trees excluded from data for burned plot (1963,68,75).

Year	1963	1968	1975	Mix	Fir
1963	-	59	35	44	31
1968		-	56	44	35
1975			-	26	31
Mix				-	77

Table 6 -- Mean percent similarity between breeding avifaunas of each successional stage and the other 4 stages.

Data source	Successional stage				
	1963	1968	1975	Mix	Fir
From Table 4	47.3	49.0	37.5	48.5	49.8
From Table 5	42.3	48.5	37.0	47.8	43.5

DISCUSSION AND CONCLUSIONS

Secondary succession is predictable and inevitable to the degree that earlier plants create an environment less favorable for themselves than for their successors (Horn 1974). In our study fire nearly destroyed the existing forest, creating soil and light conditions ideal for establishment of pine and brush (Biswell 1974, Weaver 1974). As the pine canopy closes, white fir will come to dominate because unlike pine and most brush it is shade tolerant and can reproduce under a forest canopy. A white fir forest could, then, be considered the final successional stage in our study area. However, we were unable to locate any such stands near our plots. Weaver (op. cit.) considered white fir only as a component of the "mixed conifer" forest type of western North America. These observations are powerful testimony to the frequency and importance of fire in this part of the world. Succession rarely runs to completion before the next burn. Pure stands of red fir do occur in the Sierra Nevada at elevations at and above that of our burned plot (Oosting and Billings 1943); fires there are less extensive (Kilgore 1971). We studied one of these as a best approximation to the hypothetical white fir stage on our study area.

Changes in community composition and species diversity which have occurred or which we predict for the Donner Ridge burn do not conform in all aspects with widely held generalizations about secondary succession. For example, Odum (1971) notes that both the richness and equitability components of species diversity are likely to be lower in "developmental" than in "mature" stages of succession. Odum (1975:155) also observes that "those species that are important in the pioneer stages are not likely to be important in the climax." Horn (1974:30) concluded that "the diversity of the climax must be lower than that of some preceding stage" and that (p.35) "intermediate

stages of succession are likely to be mixtures of early or late successional species, and hence to have higher diversity than either early or late stages." Horn (op. cit.) does stress that these are only generalizations and not always true.

Our data for plant populations support these generalizations, insofar as the successional pattern consisted of unimodal pulses of brush, then pine, and finally fir (table 1). However, it is evident that the brush stage was not a necessary precursor to the pine stage, since pine seedlings established themselves very early following fire.

Results of the breeding bird censuses fail in most aspects to support generalizations about succession. We found high early avian species diversity, followed by a decline when the plot became brush-dominated in 1975 (table 3). If the red fir forest is a realistic model of a white fir forest, diversity of breeding birds should continue to increase into the final stage of post-fire succession. Furthermore, the most distinctive avifauna we studied occurred at the intermediate 1975 brush-pine stage of succession (table 6).

It is generally agreed that the composition of a bird community is tied in large part to habitat structure (e.g., MacArthur et al 1962, James 1971, Bendell 1974). Actually, the structure of a recent burn resembles in some ways an open, mature forest. Snags remain standing and the ground is clear. The resemblance is made stronger if, as in this study, a few mature trees are spared by the fire. Later, when the snags have fallen and when brush and young trees crowd together, the habitat becomes structurally different and less heterogeneous (Beaver 1972). It was then that bird species diversity reached a low point, and the avifauna became characterized by species missing from or rare in earlier and later stages (Bock et al, in press).

The structure of the fir forest may explain its high bird species diversity. Although the number of woody plant species was very low (table 1), individuals were distributed unevenly in the forest, creating a patchy environment (Bock and Bock, unpubl. data). There were open areas with scattered mature trees, dense forests, clumps of saplings, grassy spots, and even mossy banks within a few hundred m^2 of forest. These patterns were due in large part to mesotopographic gradients within the forest site (Billings 1973).

In summary, much of the variation we found in bird species diversity and avian community composition probably can be attributed to differences in habitat structure. However, there remains one additional and very important consideration. As Udvardy (1969) has noted, most birds of western coniferous forests are habitat generalists. Natural selection clearly has favored birds capable of living in a variety of community types, presumably because the birds always have encountered a highly patchy environment. While we found the bird species diversity of a fir forest to be high, there were no species restricted to it. Only 8 of 34 species recorded during our investigation never were found breeding on the burned study plot. Clearly, most bird species have taken the "main chance" by evolving an ability to utilize various stages of early post-fire succession. We find these results and others discussed in this paper to be strong evidence for the role of fire in shaping the evolution of plants and birds in the Sierra Nevada.

ACKNOWLEDGMENTS

A. Starker Leopold, Vernon Hawthorne, and Marshall White kindly have made available all facilities of the Sagehen Creek Field Station. Thanks are due to Cate Cabot, Vernon Hawthorne, and Martin Raphael for field assistance. Ronald Pulliam and George Millikan offered careful and constructive comments on a earlier version of this paper. This study was supported in part by a grant from the University of Colorado Council on Research and Creative Work. Finally, we would like to thank James R. Sweeney, who first taught us about fire ecology in general, and who inspired us to study the Donner Ridge burn in particular.

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PRESENT MANAGEMENT PROBLEMS AND STRATEGIES

ON TABLE MOUNTAIN, SOUTH AFRICA[1/]

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Abstract: The unique flora of Table Mountain is under considerable human pressure because it is surrounded by a major metropolitan area. A vegetation survey from aerial photographs and ground checks to ascertain the impact of humans, fire and alien plants and animals indicated a poor conservation status. Consolidation of ownership and detailed ecological research are essential for co-ordinated management.

Key words: Fynbos, Fire, Table Mountain, Management, Recreation.

INTRODUCTION

Table Mountain forms the northern end of the Cape Peninsula mountain chain, and lies at 34°S and 18°25'E. It is a rugged massif consisting of a hard Table Mountain Series sandstone cap (du Toit 1954) overlying Malmesbury Shale and Cape Granite. In essence the Mountain comprises two plateaus: the upper, or Front Table, having a summit at approximately 1 000m and the lower, or Back Table, having a summit at approximately 650m. The general topography of the area is, therefore, characterised by moderately wide, nearly level plateaus in the upper elevations, falling away to very steep and even perpendicular cliffs of hard sandstone, to more gentle lower slopes of softer, more deeply weathered granite and shale. The topography and geology are closely linked to the soil zones. The soils of the Table Mountain Zone are generally very shallow

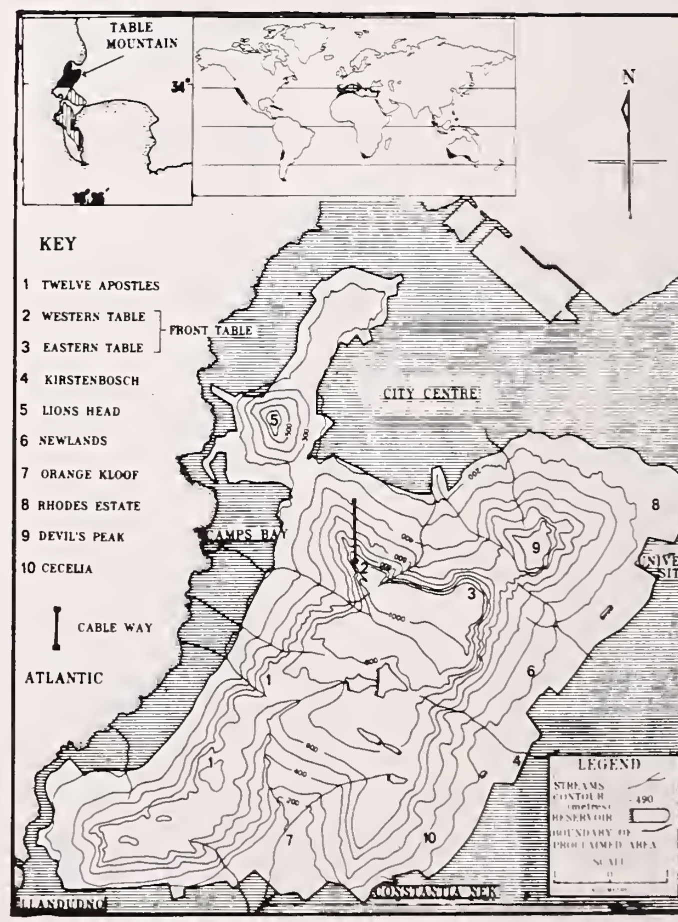

Figure 1--Topographic and location maps of world mediterranean zones, Cape Peninsula and Table Mountain

[1/]Presented at the Symposium on Environmental Consequences of Fire & Fuel Management in Mediterranean Ecosystems, Palo Alto, Calif. Aug. 1-5, 1977.

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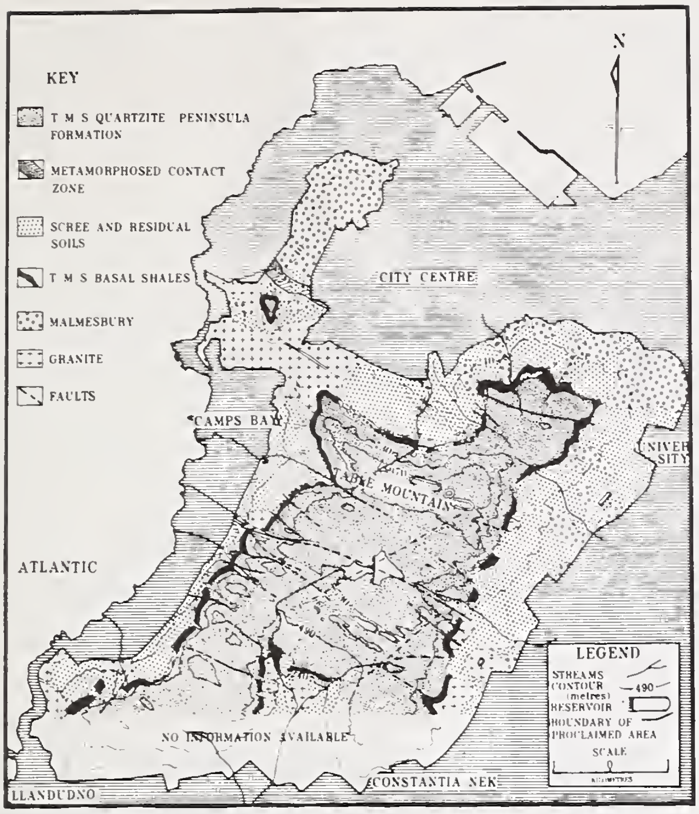

Figure 2--Map of the major geological formations on Table Mountain.

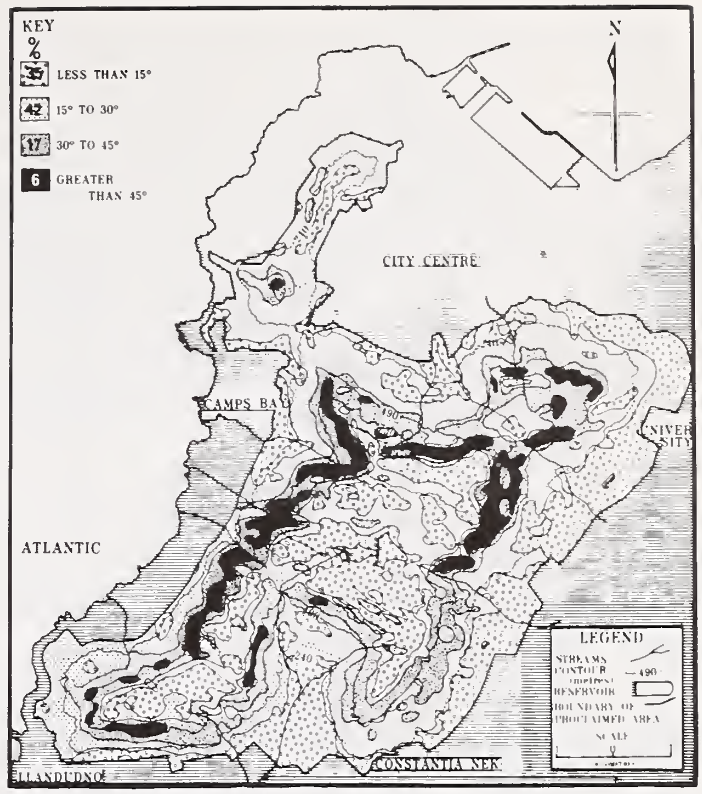

Figure 4--Map of the major soil zones of Table Mountain.

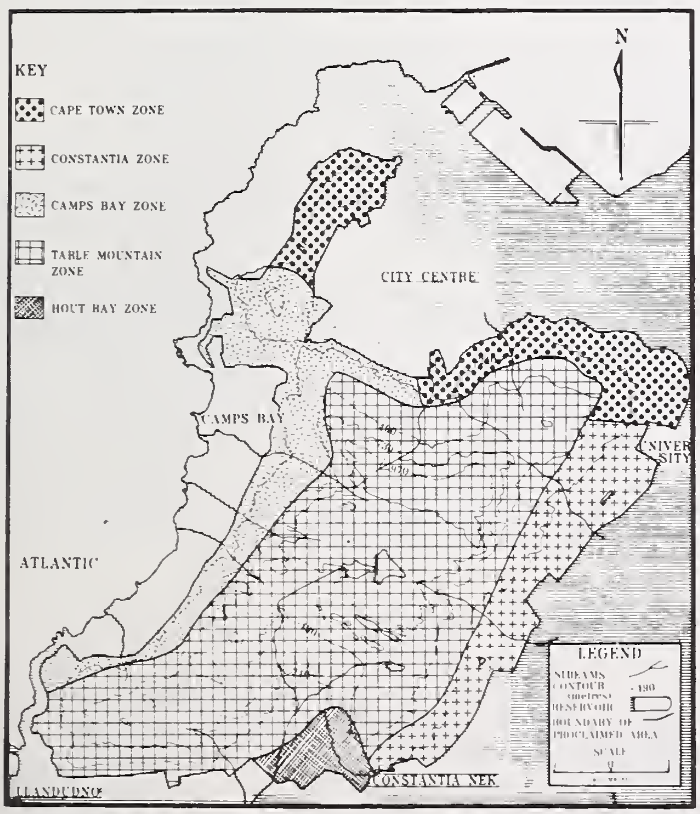

Figure 3--Slope map of Table Mountain. The percentage of the total area occupied by each of the four slope categories mapped is given.

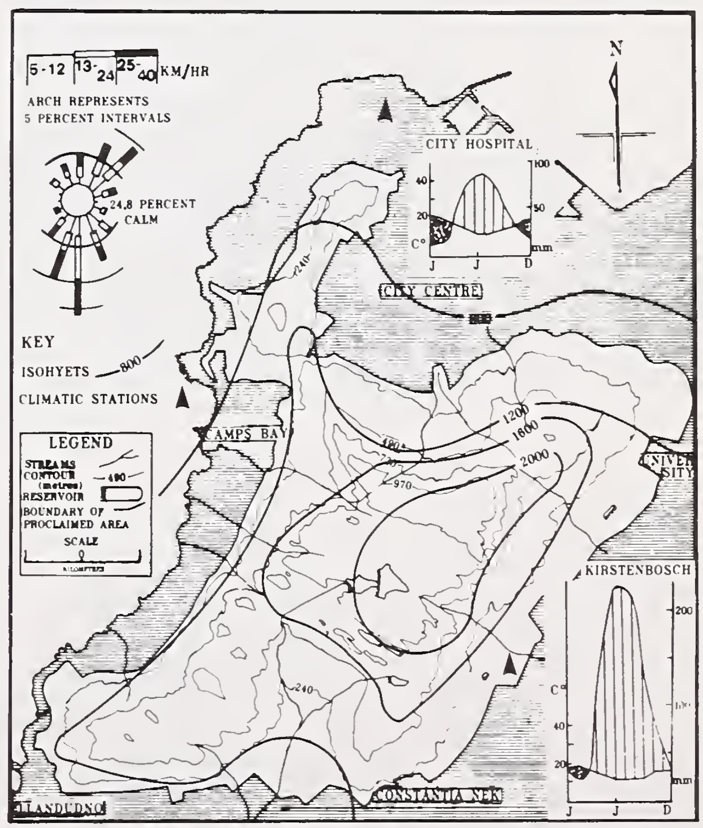

Figure 5--Climate map of Table Mountain showing the rainfall isoheyts, annual wind rose data, and Walter and Leith (1960) climate diagrams for selected locations.

(<300mm), sandy to gravelly, and tending to be waterlogged in the wet season because of the underlying impermeable bedrock. These soils are generally infertile with a pH of less than 4, and not very susceptible to erosion except on steep slopes. The soils of the Camps Bay, Cape Town, Constantia and Hout Bay Zones are generally deeper (300 to >1 000mm in parts), sandy-clay-loams, relatively free draining, more fertile, with a pH of less than 5, and are moderately to readily susceptible to erosion (Smith-Baille, Rudman, Oosthuizen, Ellis & Dohse 1976).

Topography plays a dominant role in determining the meso-climate of Table Mountain. Most rain falls on the plateaus and on the southeastern slopes of the Mountain; which also receive least insolation. The western and northern slopes are drier. This meso-climate pattern is reflected in the distribution of plant communities, for example forest (Campbell & Moll 1977) and tall, wet Fynbos occurs on the eastern slopes and plateaus, and short, dry Fynbos occurs on drier sites (Adamson 1927; Moll & Campbell 1976). Additional moisture in the form of low, southeast cloud (Marloth 1905, Nagel 1961) is particularly important during the hot, dry, windy summer months, effectively increasing precipitation. Unfortunately little work has been done on the significance of this, but landowners, with pumping rights from the streams that drain the eastern watershed, know that these streams have an increased flow in the morning following a night of southeast cloud over the Mountain in December, January and February (E.A. Schelpe pers. comm.).

ANTHROPOGENIC INFLUENCES

With the arrival of pastoral man on the Cape Peninsula some 1 500 to 2 000 years ago (Schweitzer & Scott 1973) and later the arrival of the European settlers in 1652, the pattern of human use of mountain Fynbos areas such as Table Mountain changed dramatically. Changes of particular note were more frequent and widespread burning (Taylor 1977, Kruger 1977a), the exploitation of the existing meagre timber resources (Bolus & Wolley Dod 1903, Sim 1907), the introduction of alien plants (Wicht 1945, Hall 1961, Taylor 1975, Hall & Boucher 1977) and animals (Lloyd 1975), and the cultivation of large tracts of land. Hall (1977) estimates that 61% of the Cape Floral Kingdom has been taken over for human usage, leaving a mere 1,8 x 10^6ha covered by natural vegetation.

The continual down-grading of the remaining Fynbos communities is causing grave concern to conservationists. Table Mountain, situated within a major metropolitan area (Cape Town's population is nearly 1 x 10^6), and having over 2 x 10^6 day users p.a., is particularly threatened. Attention has been drawn to its poor conservation status (Luckhöff 1951, Anon 1974, Moll & Campbell 1976), with the result that the South African Government has appointed a commission of enquiry into the future control and management of the Mountain (Government Gazette 5581 of 1977).

CURRENT MANAGEMENT STATUS

Under the present management régime Table Mountain is under the direct control of five public authorities, each being responsible for their own section of the Mountain. There is, for example, forest land (35%), a botanic garden (4%), a park (5%), a nature reserve (50%) and some privately owned land (6%). In this paper we are concerned with the indigenous plant communities (62%), the management of which, with the exception of certain wild fire protection measures, is ineffectively co-ordinated.

Currently the major problems facing the conservation status of Table Mountain, apart from the lack of co-ordination of management, are the human pressures, the encroachment of alien plants and animals, soil erosion, and fire. In fact it could be said that fire and human abuse, the latter also causes the former, are at the heart of the problem.

THE IMPACT OF FIRE

It was generally accepted some 50 years ago that Fynbos fires resulted in a general deterioration of the plant communities, an increase in xerophytism and a decrease in the preponderance of phanerophytes (Marloth 1908, Adamson 1927, 1935, Compton 1926, Pillans 1924, Levyns 1924). It was then advocated that there should be a greater degree of fire protection in Fynbos and the weight

of scientific opinion swayed management to accept that too frequent burning was harmful. Recently it has been suggested that an 8 to 15 year fire cycle, "to maintain vigorous fynbos in all its attractive diversity of forms and species", is optimum (Taylor 1977). Wicht (1973) showed that this burning régime gives the best stream flow. Today most of the mountain Fynbos areas are managed by the Dept. of Forestry whose main objectives are water and nature conservation (Bands 1977). Their programmes are reasonably effective

Table 1--The effect of Fynbos and afforestation on stream flow. Data from Jonkershoek, mean annual rainfall 1 500mm.

Treatment	Stream flow	
	mm	%
Fynbos (controlled burning 7-year cycle)	800	53
Pine plantation (15 years rotation)	730	49
Fynbos (15 years protection)	600	40
Pine plantation (30 years rotation)	550	37

because, in the more sparsely populated areas, human interference is less of a problem. On Table Mountain, however, most of the indigenous plant communities have been burnt, at least once, within the last 10 years (see fig.6), in spite of strict fire protection measures by the authorities. In fact records show that some 53 to 244 wild fires occur

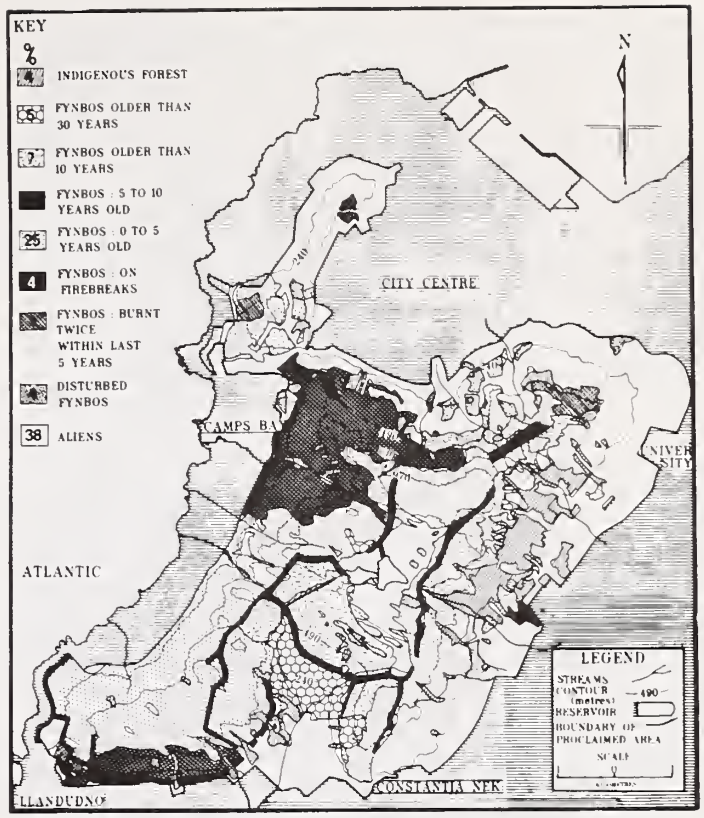

Figure 6--Map of Table Mountain showing the status of the vegetation in 1975 (after Moll & Campbell 1976). The percentage of the total area occupied by each vegetation unit recognised is also given.

annually on the Mountain (in wet and dry years respectively) in summer. It has been suggested that a reasonable fire interval on Table Mountain would be from 12 to 15 years (McLachlan & Moll 1976), but under natural conditions this may have been even longer (30 to 50 years). However, with increased age of Fynbos after burning there is an increased fire hazard because of the

Table 2--The number, seriousness, and estimated total cost of wild fire prevention and control on Table Mountain.

Season	Rainfall (Kirstenbosch 1414mm 35 year average)	No. of fires	No. of serious fires*	Total area of fynbos burnt (ha)	Costs R(S.A.)
1972/73	861	244	21	1 200	50 000
1973/74	1 046	116	4	210	45 000
1974/75	1 664	110	3	380	90 000
1975/76	1 739	94	3	400	70 000
1976/77	1 999	53	none	360	130 000

*Those burning areas larger than 1 ha.

greater abundance of fuel, and because of an increasing quantity of dead material - a process termed senescence (Taylor 1977, Kruger 1977a, Bands 1977). It must be noted that not all old Fynbos on Table Mountain can be termed senescent, in fact the Fynbos in Orange Kloof, which has been protected from fire for more than 30 years is dynamic, currently being invaded by forest pioneers, and with further protection will develop into a closed forest community (McKenzie, Moll & Campbell 1977). However, on more exposed sites, where forest species are unable to survive, the degree of senescence of old Fynbos is high. A study of senescence is, therefore, necessary to plan appropriate fire intervals in order to achieve the best possible vegetation cover and effectively protect human dwellings and plantations by maintaining low fuel levels. It is also obvious that some form of educational programme of the users of Table Mountain as well as some form of policing of the area in an attempt to prevent the illegal firing of the vegetation, is an essential part of management.

Fire and alien plants

The invasion of *Pinus pinaster*, which is one of the important aggressive invaders on Table Mountain (Moll & Campbell 1976), is known to be enhanced by fire (Kruger 1977b). This is also true for *Hakea* spp. (Wicht 1945, Hall 1961) and for various Australian *Acacia* spp., particularly *A. mearnsii*, *A. longifolia* and *A. saligna* (Roux & Middlemiss 1963). On Table Mountain all areas of indigenous vegetation are threatened by alien encroachment.

Once the alien plant species become established the indigenous species are smothered and there is a general reduction not only in cover but in species diversity (Cowling, Moll & Campbell 1976). Subsequent removal of the alien species can lead to soil erosion, particularly if the felled areas are burned, as has happened on Devil's Peak and on the northern slopes of Table Mountain. Since large portions of Table Mountain are covered by alien plants, their removal will have to be carefully planned and monitored, and injudicious felling, such as has already occurred, must be avoided (Moll & Campbell 1976, McLachlan & Moll 1977).

Fire and alien animals

On Table Mountain it is currently estimated that there are some 600 wild Himalayan Tahr. These goats are known to be the cause of much of the erosion on the Mountain (Lloyd 1975), particularly on the northern slopes and on Devil's Peak. These goats are particularly fond of utilizing newly burned areas for grazing. Attempts are being made to control these pest animals and perhaps even eradicate them, but the terrain is difficult and sentimental public opinion is not particularly favourable. However, it has been accepted that it is essential that their numbers must be drastically reduced and a culling programme, although inadequate, is operational.

Fire and natural vegetation

Very little work has as yet been done on the impact of fire on the natural vegetation of Table Mountain, but various research programmes are being planned. Some observations and data are available and although inadequate may serve to indicate the direction of future research.

Adamson (1935) noted a temporary dominance of some communities by *Euryops abrotanifolius* three years after a burn and also suggested that in some sites there is an increase in the number of geophytes when the community is burnt repeatedly. Density data of *Watsonia pyramidalis* obtained from Orange Kloof supports Adamson's observations.

Table 3--Average number of *W. pyramidalis* plants present per ha in various aged Fynbos communities in Orange Kloof

Estimated age (yrs) of vegetation since last burn	Status in Feb. 1976	Average density of *W. pyramidalis* plants/ha
45	unburnt	300
45	burnt	1 500
30	unburnt	480
30	burnt	5 740
10	burnt	13 000

There is also evidence to suggest that on more regularly burnt sites there is an increased occurance of certain plant species, such as *Helichrysum vestitum, Stoebe cinerea, Pelargonium cucullatum, Ehrharta ramosa, Merxmullerii macrantha, Pentachistis curvifolia* and *Restio triticeus* (McKenzie, Moll & Campbell 1977). In addition, a study of established fire-breaks revealed a general decrease in total plant cover and the virtual elimination of the proteoid element, as well as an increase in grass cover. This increase in the percentage cover of grasses on fire breaks has been noted in other areas.

A preliminary study in 1975 of regeneration after fire showed that forest is virtually completely destroyed by fire, and that the rate of regeneration of Fynbos is apparently dependent on whether the site is "wet" or "dry" and on the age of the community prior to the burn. Frequently burnt dry sites showed poorest regeneration rates (McLachlan & Moll 1976).

CONCLUSIONS

1. Before Table Mountain can be properly managed consolidation of ownership and the production of a scientifically planned management programme are pre-requisites.

2. With the increasing effectiveness of fire prevention it will become necessary to determine the best season, frequency and conditions for burning, to maintain vigorous and diverse plant communities. In addition the present network of fire-breaks needs to be examined to assess whether these are all correctly located.

3. The users of the Mountain need to be educated to take more care of the massif.

4. Better policing of the area to ensure control is essential.

5. The channelling of users by maintaining and perhaps constructing a well planned path network will assist in proper management.

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FIRE ECOLOGY AND MANAGEMENT

OF PHRYGANA COMMUNITIES IN GREECE[1]

Vasilios P. Papanastasis[2]

Abstract: Available information on fire ecology and its management on phrygana communities, a distinctive plant formation found in areas with a Mediterranean-type climate and degraded soils in Greece, is summarized. Phrygana species and the associated herbaceous vegetation have been adapted to a regime of repeated wildfires occurring there for centuries. This regime is perpetuated by the shepherds on purpose to increase their grazing capacity for sheep despite the official policy for total fire exclusion. It is suggested that controlled fire coupled with proper grazing management should be applied as a way to rational fire management of phrygana communities.

Key words: Phrygana, fire ecology, fire management, controlled fire, Sarcopoterium spinosum, Phlomis fruticosa.

INTRODUCTION

The term "phrygana" means xeromorhpic and flammable half-shrubs (less than one meter height). It was originally used by Theophrastos while Heldreich, a German botanist, introduced it into the modern literature in 1878. Plant communities dominated by phrygana are known as "tomilaris" in Spain, "batha" in Israel and "garrique" in Southern France (Rechinger und Rechinger-Moser 1951, Naveh 1974).

Phrygana communities are a physiognomically distinctive plant formation. They grow on dry, rocky, shallow and degraded soils and in regions with long, dry and hot summers and mild and rainy winters. Thus, they are found in the part of Greece with the harshest climatic and edaphic environments (fig.1).

There is no general agreement among scientists as to whether phrygana are climax or modified communities by man's action. Some phytosociologists consider them as disclimaxes or facies caused by wildfires and overgrazing (Debazac et Mavrommatis 1969, Dafis 1973). Others, although they accept that their present broad distribution is due to anthropogenic influences, they believe that at least in certain areas with adverse ecological environments phrygana constitute the climax vegetation (Rechinger und Rechinger-Moser 1951, Lavrentiades 1969, Litav and Orshan 1971).

Phrygana communities occupy more than one million hectares in Greece. They are important areas for livestock grazing especially for sheep in the winter period and they are used as such extensively.

Fires have been a common phenomenon in phrygana communities for thousands of years. The purpose of this paper was to sum up the available information on the effects of fires in these areas and discuss the use of controlled fire for their rational management.

SUBTYPES OF PHRYGANA COMMUNITIES

Because of their broad distribution, phrygana communities are dominated by different species of half-shrubs depending upon the particular soil type and the specific microenvironment. They may be distinguished into the following subtypes:

1/ Presented at the Symposium on Environmental Consequences of Fire and Fuel Management in Mediterranean Ecosystems, Palo Alto, Calif. Aug. 1-5, 1977.

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Figure 1--Approximate distribution of phrygana communities in Greece

Sarcopoterium spinosum communities

This subtype is dominated by Sarcopoterium spinosum (L.) Spach, a dwarf rosaceous shrub of less than 50 cm height with branches ending in dichotomous, leafless thorns (fig.2). Other half-shrubs found include Coridothymus capitatus Reichenb., Ononis spinosa L. and Calycotome villosa L.K.

Figure 2--Sarcopoterium spinosum

S.spinosum communities are a common vegetation type in the eastern Mediterranean countries except Egypt, usually grown on calcareous soils (Litav and Orshan 1971). In Greece, they are widespread in the southern part of the country, especially in the Aegean islands, and extend up to its northern part (fig.1). They are confined to areas with less than 500mm annual rainfall. The soils where they usually grow are rocky and friable without active calcium (Debazac et Mavrommatis 1969).

Phlomis fruticosa communities.

This subtype is dominated by Phlomis fruticosa L., a conspicuous shrub, 60-90cm in height with greyish, woolly and oval leaves and cottony branches terminating at whorls of yellow flowers (fig.3). Quercus species are also found in these communities of which Q.coccifera L. is the most common.

Figure 3--View of a Phlomis fruticosa community

P.fruticosa communities are widely distributed in the western and central mainland and they are found in certain Aegean or Ionian islands too (fig.1).They grow on areas with more than 500mm annual rainfall and on soils developed mainly on hard limestone (fig.3).

Other phrygana communities

The remaining three subtypes are less important, because they either have restricted distribution such as the Coridothymus capitatus and Ballota acetabulosa Benth. communities, or have wider distribution but occupy relatively small areas such as the Cistus spp.communities (Debazac et Mavrommatis 1969) (fig.1).

The discussion that follows will be centered at the first two subtypes, S.spinosum and P.fruticosa communities, which are the most important in terms of distribution.

FIRE ECOLOGY

Frequency of fires

Fires are very frequent in the phrygana communities. Approximately 15% of the wildfires occur in lands covered mainly by phrygana.These fires burn about 4,000 ha representing 30% of the total area burned each year (Kailidis et al. 1975).

Most of these fires are set by shepherds on purpose to increase the grazing capacity for sheep. Burning of phrygana is a common practice in several Aegean islands, especially in Crete, on S.spinosum communities and in Thesprotia, western Greece, on P.fruticosa communities.It is an uncontrolled process which causes severe damage to these ecosystems.

Burning for range improvement purposes is being practised for unknown but very long time in the phrygana communities.Fires are set in the summer period or early fall. They are rotated every 3-5 years, whenever the undesirable to sheep phrygana have become too dense to allow desirable herbaceous vegetation to grow and free circulation of the grazing animals is hindered (Papanastasis 1976).

It seems however, that periodical burning is not an unwise practice. Experimental use of fire in different seasons of the year showed that S.spinosum plants did not burn easily unless enough dead twigs had existed on them. This dead material required a minimum of three years period since the last fire to get accumulated[3/]. A 3-5 years fire cycle, depending upon the soil type, was found to be the case in the P.fruticosa communities, too (Papanastasis,1976).

Adaptations to fire

The recurring fires regime in phrygana communites has led to the evolution of special features or mechanisms by phrygana species which make them more flammable and at the same time more fire dependent for optimum growth and health.

Flammability

Phrygana species have developed several features that make them very flammable. Their leaves are, in general, small, hairy, with thin cuticles. Their shoots are slender, hairy in most species and their twigs fine and loosely arranged. These features facilitate their quick response to the changing weather conditions, such as the reduction of their moisture content in the summer which in turn will increase their flammability (Biswell 1974).

Another feature is the dead shoots that mature plants retain. In S.spinosum plants this dead material is composed of fine twigs and spines and it is highly flammable; its percentage weight increases with age as opposed to the weight of the live shoots:

	Live %	Dead %
1 year-old sprouts	100	0
2 year-old sprouts	67	33
3 year-old sprouts	55	45
mature plants	22	78

Still another feature may be the shedded leaves at the base of the plants during the summer period which help the fire to spread quickly over their crowns (Papanastasis 1976). Leaf shedding in the summer is a physiological adaptation to drought remarkably exhibited by S.spinosum (Orshan 1971).

Stump sprouting

Sprouting may be considered as an adaptation to recurring fires (Biswell 1974).

P.fruticosa sprouts vigorously from dormant buds located at the root crown (fig.4). These buds remain unharmed during fires and spring up almost immediately after burning. An average of 10 sprouts per burned plant was counted in Thesprotia, western Greece (Papanastasis 1976).

S.spinosum sprouting depends on the particular environment it grows in. In a community of northern Greece 95% of the burned plants were revived with sprouts. However, in Crete where the conditions are drier only 15% of the burned plants sprouted[3/].

No sprouting was observed in Cistus species in a community of northern Greece (Papanastasis 1977).

Figure 4--Root crown of Phlomis fruticosa dotted with dormant buds.

3/Papanastasis,V. Effect of time and frequency of burning on a Sarcopoterium spinosum community. Unpublished data.

Seed germination

Phrygana seeds are not only heat resistant but their germination capacity is heat stimulated too. This can be considered as another adaptation to fire.

As many as 1900 seedlings per meter square were counted under burned mother plants of S. spinosum five months after the fire. The population was reduced by 73% four months later (fig.5)[3/]. Also, 200 seedlings of Cistus salvifolius and C.monspeliensis per meter square were found nine months after the fire. The population was reduced by 31% in the second and by 5% in the third year after the fire (Papanastasis 1977). On the other hand, no mass seedling emergence after fires was observed in P.fruticosa communities (Papanastasis 1976).

Figure 5--Seedlings of Sarcopoterium spinosum

The above field findings were verified with laboratory work. Papanastasis and Romanas (1977) heated phrygana seeds to 50, 75, 100, 125 and 150°C from 1 to 30 minutes. They found that seed germination was increased significantly in 100 and 125°C for S.spinosum seeds from northern and southern Greece respectively;in 125°C for Cistus monspeliensis and in 75°C for C.incanus. On the contrary, seed germination of P.fruticosa was most favored by 5-minutes heating in 50°C, a temperature normally attained by the soil surface in the summer and without fire. In addition, seeds of S.spinosum and C. monspeliensis survived in 150°C while the ones of C.incanus and P.fruticosa in 125°C.

Herbaceous vegetation

Adapted to recurrent fires are not only the phrygana species but also the herbaceous vegetation which usually grows among them. An excellent example is Andropogon hirtus, a perennial grass of 50-120 cm height. This species retains its old growth which makes it highly flammable and at the same time dependent on fire for revival through its vigorous sprouting.

Annual species are also adapted to fires because of their being at the seed stage in the summer when phrygana fires occur.

Size and distribution of fuel

The size of fuel in phrygana communities varies according to the particular subtype,soil type, degree of grazing and time passed since the last fire. In a mature S.spinosum community grown on a fair site and protected from grazing for four years biomass production was found to be 4,500 kg/ha with a relation of phrygana to herbage equal to 1.8/1[3/]. In an analogous site in P.fruticosa commutities of Thesprotia, the biomass production was found to be 5,500 kg/ha or 1.7/1 the relation of phrygana to herbage[4/]

Fuel distribution is uniform only on good sites and old stands where phrygana get thick with no or very little herbaceous vegetation intermingled.However, the usual case is a discontinued fuel distribution characterized by the scattered phrygana and the herbaceous vegetation in between, usually grazed up.The percentages of the components of ground cover in the two communities of phrygana whose biomass data were given above were:

	S.spinosum	P.fruticosa
Phrygana	30	25
Herbaceous vegetation	38	63
Soil and rocks	32	12

Behaviour of fires

The relatively low size of fuel and its discontinuity usually results in light fires compared to the fires in other vegatation types such as maquis or forests. This is also verified by the thin layer of ash, usually black, which is left on the ground.

Herbaceous vegetation is the main carrier of fire. Andropogon hirtus plays a vital role in this process;also, species of Asphodelus, Circium and Carduus. Therefore, in overgrazed stands carrying the fire is problematic (Papanastasis 1976).

To get a good fire and have the phrygana species burned up shepherds are forced to choose hot and windy days in the summer to set the fires which in turn would make their control unfeasible

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4/Papanastasis,V.and A.Gogos.Identification of range sites in the Phlomis fruticosa communities of Thesprotia,Greece.Unpublished data.

Post-fire succession

Succession after fire is fast in phrygana communities compared to other Mediterranean vegetation types (Le Houérou 1974). Phrygana sprouts attain one third of their original height by the end of the first growing season and they produce seeds in the second season after the fire. Biomass production was found to be 3,000 kg/ha in a P.fruticosa community eight months after the fire (Papanastasis 1976);in a S.spinosum community on the other hand it was 1,200 kg/ha in the first year, 1,600 kg/ha in the second and 2,800 kg/ha in the third year after the fire[3].

Annual species dominate the phrygana burns in the first year and they decline thereafter as in other post-fire successions of the Mediterranean zone (Le Houérou 1974). Legumes are the prevailing species, especially Trifolium campestre, T.arvense, T.tenuifolium, Vicia lathyroides, Medicago praecox and M.tribuloides. Also, quite abundant are the annual grasses Gastridium lendigerum, Avena sterilis, Aegilops cylindrica and Vulpia ciliata. These species can compete heavily phrygana seedlings appearing also after the fire (Litav and Orshan 1971, Papanastasis 1976, 1977).

Environmental considerations

Soil erosion was the most serious damage that repeated wildfires have had on phrygana ecosystems through the years. In steep slopes, soil is found only in "pockets" among rocks. Although a degree of balance seems to have been attained between the phrygana ecosystem and the wildfire regime in the course of time, erosion still takes place in the steep slopes particularly by washing down the ash (Papanastasis 1976).

Escaping phrygana wildfires often cause serious destructions to olive tree orchards, livestock installations, residences and even kill people or animals.These damages have seriously predisposed the public and the policy makers against the possible benefits of fire.

FIRE MANAGEMENT

Present management model

Shepherds are using fire as a tool to suppress phrygana species and take advantage of the palatable to sheep legumes appearing in the burns one or two years after the fire. Their management philosophy is based on the model shown on figure 6.

However, the grazing management practiced is unwise. The burned communities are grazed by high numbers of sheep which enter the areas as soon as the annual species germinate. The degree of grazing use was found to be 80% in the first season after the fire for a grazing period of seven months (November through May) (Papanastasis 1976).

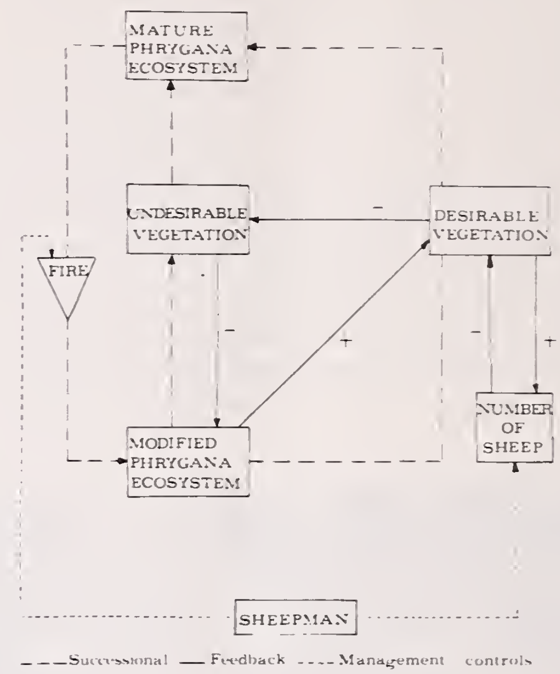

Figure 6--A compartmental model of the phrygana ecosystem.

Overgrazing has several undesirable effects Phrygana seedlings grow fast and dense due to the reduction of competition with annual grasses and forbs. Sprouting is facilitated because stumps are exposed to full sunlight and have more soil moisture available. Soil gets bare and thus more hospitable to weed or phrygana seeds which in addition are easier trampled into the soil by sheep.

Therefore, overgrazing results in speeding up the recovery of the burned phrygana and in increasing their density and distribution. This would require a new fire to temporary suppress them and the cycle goes on (fig.6).

Controlled fire

Although wildfires are devastating and detrimental to the ecosystems, controlled fire can be an effective means for improvement of grazing lands.

Controlled fire appears to be an inexpensive and natural way of controlling phrygana species and increasing the quality and quantity of forage. In a S.spinosum community, herbage production was increased by 15% with a winter fire and by 36% with a September fire compared to the control. However, the increase was much higher since most of the herbage in the control was unavailable to animals[3].

Selection of the areas for controlled fire management should be of prime consideration. It has been suggested that fire ought to be totally

excluded from communities with steep slopes (30% or more), where its beneficial effects are in doubt and its control problematic, and be restricted to areas with good soil and gentle slopes[4]/.

Proper time of burning is also another important consideration. In some S. spinosum communities winter fires have more desirable effects than summer fires and they can be controlled easier. Also, fires in years of low seed production will produce fewer seedlings than in years with high seed production. Finally, securing hot fires will result in killing more S. spinosum plants than light fires[3]/.

However, controlled fire will not kill phrygana. It will rather stimulate their regrowth. Therefore, it has to be used periodically in order to keep the phrygana system to a state which meets the management objectives.

Proper grazing management

The beneficial effects of controlled fire will not last unless fire management is coupled with proper grazing management as well.

This includes: 1) deferring grazing in the first year after the fire so that phrygana seedlings are knocked out by the competing annual species or even enhancing this process by planting on the ash competitive annual grasses; 2) light grazing in the following years to prevent exposing of stumps to full sunlight; 3) using goats for grazing instead of sheep because they can browse a little on phrygana, combined with cattle where it is feasible; and 4) using mechanical means or chemicals for supplemental control of phrygana where it becomes necessary.

All these and probably other grazing conditions should be secured prior to using fire as a management tool in phrygana communities.

DISCUSSION AND CONCLUSIONS

Fires, either natural or man caused, have been part of the Greek environment for thousands of years (Liacos 1974). Phrygana communities seem to have evolved in a regime of frequent fires. This is indicated by the adaptive mechanisms and features that phrygana species and the associated with them herbaceous vegetation have developed to become more flammable and at the same time more fire dependent for revival. Moreover, P. fruticosa plants would not live longer than 20-30 years unless they are burned for renewal (Papanastasis 1976). The same was observed in S. spinosum plants too.

Phrygana communities are natural in certain extreme habitats within the Mediterranean zone, where fire is an important ecological factor (Naveh 1974). This was shown for S. spinosum communities by several investigators (Rechinger und Rechinger-Moser 1951, Lavrentiades 1969, Litav and Orhan 1971). It is likely that climatic climaxes exist in restricted areas for the other subtypes too.

However, the present broad distribution of phrygana communities is the result of man's activities since Neolithic times. P. fruticosa communities have been characterized as pyrozootic climaxes, namely vegetation types whose presence is based on recurring wildfires and overgrazing, especially by sheep (Papanastasis 1976). This characterization may be extented to other phrygana subtypes too; it means that if fires and overgrazing are excluded phrygana communities may be phased out in several areas and replaced by more advanced plant communities such as shrublands or even forests.

Although total fire exclusion has been the official fire policy in Greece for many years now (see also L.G. Liacos' paper in this Symposium), it never worked in phrygana communities. This is because shepherds are convinced that fire is the only means to increase the grazing capacity of these areas for sheep and make their living. Therefore, total fire exclusion resulted in the violation of the fire laws and thus to the perpetuation of the wildfire regime.

On the other hand, complete phasing out of phrygana communities, as total fire exclusion policy aims to, may not be desirable to all phrygana regions. This is because a considerable part of their distribution zone can be converted to productive grazing areas by means of rational fire management.

Therefore, excluding fire from the poor sites and using controlled one in the better sites coupled with proper grazing management appears to be the only solution to the phrygana communities problem. In doing so, the sheepman of the model on figure 6 must be replaced by the rational operator who will effectively combine controlled fire and grazing to manage phrygana areas for maximum sustained yield.

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ASPECTS OF THE ECOLOGY OF THE CAPE OF GOOD HOPE NATURE RESERVE IN RELATION TO FIRE AND CONSERVATION[1]

H.C. Taylor[2]

Abstract: The three landscape types in the Reserve are described and the rare species list examined to show that conservation management must ensure survival of the following endangered or fragile elements: members of typical or endemic families of the Cape flora; seed - regenerating species; and rare habitats. Fire regeneration strategies of three taxa are compared to show that fire is an essential tool in such management, both to maintain the Cape fora and to reduce the invasive alien species that are replacing fynbos vegetation.

Key words: Rare species, conservation, endemics, fynbos, fire, invasive species.

Contrary to the belief still widely held by visitors to our country, Cape Point is not the southernmost tip of the African continent. That distinction must go to Cape Agulhas, a low, unimpressive headland 150 km to the east and half a degree further south. Yet the austere beauty of Cape Point has been recognized ever since Francis Drake, four centuries ago, proclaimed it "the most stately thing and the fairest Cape we saw in the whole circumference of the earth".

A century before, in 1488, Bartholomew Dias rounded the Cape unwittingly, for he was blown past it, out of sight of land, by a great storm. Though he was obliged to return home without completing his mission, he was the first Portuguese navigator to establish that a sea route to India was possible; and it was probably his King, John II of Portugal who, recognizing Cape Point as the key to this route, first named it Cabo de Boa Esperanza, the Cape of Good Hope.

The nature reserve that bears this name is 7680 ha (about 30 square miles) in area and forms the final segment of the Cape Peninsula. The Reserve has three major land forms: uplands, plateau and coastal shelf. The uplands, built from Table Mountain sandstones of the Cape geological system, bound the Reserve as a broken range of peaks up to 360 m high along the False Bay coast in the east, and enclose the plateau as a line of hills (275 m) in the north and as a low escarpment rim (60 m) parallel with the coast in the west. The sandstones weather to an acid, nutrient-poor, sandy lithosol that bears typical mountain fynbos vegetation, widespread elsewhere in the southwestern Cape. The central plateau, 60-150 m in altitude, is roughly triangular in shape, with its base in the north and its apex in the south. With outliers it comprises almost 1/3 of the area of the Reserve. Nearly flat land of this extent is rare in the mountain systems of the southwestern Cape. The plateau is underlain by horizontal sandstone strata which are normally close to the surface but sometimes covered by a metre or more of fine humic soil. The poor drainage and variable soil depth, together with the strongly seasonal rainfall, have produced varied and extreme edaphic conditions, each with its local specialized "marsh fynbos" community such as stream banks, seepage steps and small seasonal pans.

The coastal shelf on the west is usually less than half a kilometre wide. Its inner zone consists of colluvial sand washed down from the hills into a shallow, moist through where soil conditions and plant communities may resemble those of the marshy plateau. Seaward of this the littoral is rocky but several raised beaches of fine marine sand and

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[1] Presented at the Symposium on Environmental Consequences of Fire and Fuel Management in Mediterranean Ecosystems, Palo Alto, Calif. Aug. 1-5, 1977.

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some dunes of varying ages occur. Each of these habitats bears variations of littoral broad-leaved scrub or dune fynbos communities. Other dune complexes, originating at different epochs from sandy coves along the east coast, have been blown northwestward across the Reserve by the prevailing southeast winds of summer, and have stabilized and calcified to different degrees depending on their age. The oldest of the dunes bears a rare and specialized calcicole "dwarf dune fynbos".

The Cape of Good Hope Nature Reserve is unusual in having within its borders these three landscape types, each with local topographic variations, resulting in an array of plant communities, some widespread, some rare, some intergrading, some well defined. Of the twenty vegetation units distinguished in the Reserve (Taylor 1969a), two belong to the Broad-leaved Scrub Formation which is a simplified, impoverished form of the coast forests of the Knysna region 500 km to the east. They occupy scarcely 3% of the Reserve's extent, being confined to fire-free scarps near the coast and a few rock screes inland. The remainder of the communities belong to the Fynbos Formation, the basic vegetation matrix of the southwestern Cape. Typical fynbos is a closed, stratified shrubland ½ to 1½ metres tall, with restioid, ericoid and proteoid elements in varying mixture (Taylor 1972, 1977). Though the families and many genera characteristic of the Cape flora are found throughout the fynbos, the individual species are often narrowly limited in distribution. It is therefore interesting that many species of the southern Cape Peninsula are also found on the coasts and mountains of the Cape Hangklip area across False Bay (Boucher 1977) but nowhere in between. Since the coastal vegetation of the Cape Hangklip area is being destroyed by seaside development, it is essential that the rich flora of the Cape of Good Hope Nature Reserve be conserved.

There is a present known total of 1060 species of flowering plants and ferns in the Reserve, including 21 introductions. Alpha diversity is high, up to 83 species of perenially recognizable plants - that is, excluding annuals and geophytes - having been recorded in 50 m^2 samples (Taylor 1969a). While the Reserve has not a single rare or endemic vertebrate, there are at least 39 species of plants that are either endemic to it or so rare and localized that their existence elsewhere is threatened; and with the continuing pressures on wild lands in the southwestern Cape, this list may soon be lengthened. Flora conservation, not game management, should therefore be the major policy aim for the Reserve.

These endemic, rare and endangered taxa will, in the following discussion, all be lumped under the term "rare species". In considering proposals for flora conservation in the Reserve, rare species and rare communities must receive special attention. To illustrate this, I would like to examine some of the attributes of the rare species list as a whole, and some characteristics of a few of the rare species in particular.

Classifying the rare species by family and tabulating the percentage of rarities found in each family in the Reserve gives the following result:

Bruniaceae	29%
Ericaceae	19
Proteaceae	17
Restionaceae	14
Brassicaceae	9
Iridaceae	8
Orchidaceae	7
Rosaceae	6
Liliaceae	5
Mesembryanthemaceae	4
Fabaceae	1
Asteraceae	<1

Top place goes to the Bruniaceae, largest of the families endemic to the Cape Floral Kingdom. Next is a compact group with about 15 to 20% of rarities formed by families most typical of and having their greatest diversity in the Cape flora - Ericaceae, Proteaceae (section Proteoideae) and Restionaceae. These are followed by an equally distinct cluster of rarity values ranging from about 5 to 10%, comprising six families well represented both in the Cape and in other South African floras. Lastly, although the great cosmopolitan families Asteraceae and Fabaceae together comprise 18% of the total flora of the Reserve, only about 1% of their species are even doubtfully endangered. Hence, in the Reserve, the percentage of rare species in each family shows a direct correlation with the restriction of that family to the Cape flora. In conservation management, therefore, we need to take special care to ensure survival of members of the families endemic to or typical of the Cape flora.

Next, classifying the rare species by their mode of regeneration following fire (table 1), it is evident that seed regenerators - those species that are most liable to extinc-

tion if burning occurs too often or at the "wrong" season - constitute by far the largest category (19 species). Second place goes to the geophytes, many species of which were over-picked for the wild flower market before the area was reserved in 1939.

Table 1--Number of rare species on Cape of Good Hope Nature Reserve, (a) by landscape types, showing (b) total number of rares (R) and those endemic to the Reserve (E), in (c) the four fire regeneration classes: seed-regenerators (S); geophytes (G); rhizome-sprouters (Cr) and those that coppice from the base of the stem (Cb).

(a) Landscape type	(b) Rare spp.		(c) Fire regeneration classes				
	R	E	S	G	Cr	Cb	Tot.
Plateau	22	9	12	5	5	0	22
Dune	6	1	3	1	2	0	6
Plateau + dune	28	10	15	6	7	0	28
Mountain	11	2	4	5	0	2	11
Total all habs.	39	12	19	11	7	2	39

Taking the three landscape types as the units of yet another classification (table 1) we see that the moist plateau sites harbour well over half the rare species of the Reserve and no less than three-quarters of those rare species that are strictly endemic to the Reserve. The number of local endemics in an area, because they are so restricted, gives an indication of the vulnerability of their habitat. The number of seed regenerators in an area provides a similar measure. Both these categories have highest values in the moist plateau habitats which comprise a mosaic of small, localized and specialized communities.

In contrast with the plateau habitats, those of the calcified dunes, while also highly specialized, are simpler and more uniform. Occupying less than one-tenth of the Reserve, the dunes recur with little variation for at least 200 km along the southern Cape coast - always, however, of limited extent. Despite their small area, the dunes of Cape Point have a comparatively high 15% of the Reserve's rare species but only one strict endemic.

Thus, together, the uncommon, specialized habitats of plateau and dune, compared with the common, widespread mountain habitats, harbour the greatest concentration not only of rare species as a whole, but also of those, the seed regenerators and endemics, that are measures of the vulnerability of a habitat. These figures emphasize the need to exercise the greatest care in managing especially the rare habitats of the Cape of Good Hope Nature Reserve.

Careful management implies sound knowledge, and sound knowledge carries the prerequisite of intensive and thorough research. Ideally, the autecology of each rare species, especially seed regenerators, should be adequately known before fire management in its habitat is planned. Regrettably, such information is rarely available. In the Reserve the only autecological study to date is an undergraduate project by Gubb (1976) on *Staavia dodii* Bolus (Bruniaceae), a seed regenerator endemic to the Reserve's rocky hills but not as yet seriously endangered (see fig. 1). Although in the short time available Gubb's study was inconclusive, certain facts emerged which lend themselves to speculation on the role of fire in regeneration of this species. Firstly, it fruits over an extended period from late autumn to late spring. The seeds are only viable for a short time before they are infected by fungi. This infection starts while the seeds are still in the flower head where fungal spores from the atmosphere are trapped by a sticky exudation of the flowers. Soon after they fall to the ground practically all seeds are infected by soil fungi, and there is little or no regeneration in populations that have not been burnt for a number of years. If, however, fire occurs during the seeding period, the hard testa is cracked and the seed and soil are both sterilized by the heat of the fire. These sterilized seeds germinate unhindered by fungal infection and grow vigorously in the absence of competition. Thus, to maintain the species, fire must occur during the period late autumn to late spring. Such fires are unusual in the southwestern Cape and it is therefore seldom that the right conditions for adequate regeneration occur. After the summer fires that are more characteristic of our mediterranean-type climate, a marked paucity of regeneration has been observed. The present restriction of *S. dodii* may thus be due to the following circumstances: firstly, its seeds are viable only for a short time, and its seeding period is out of phase with the normal fire cycle; secondly, since young bushes bear less seed than older ones, the frequent burning that was common before the area was reserved could have reduced the regeneration potential still further.

In contrast with *S. dodii*, which has never been recorded outside the Reserve, are two *Leucadendron* species, *L. floridum* R.Br. and

L. macowanii Phillips. Before the turn of the century both species inhabited moist places scattered through the Cape Peninsula but both are now confined to small areas in the Reserve (fig. 1).

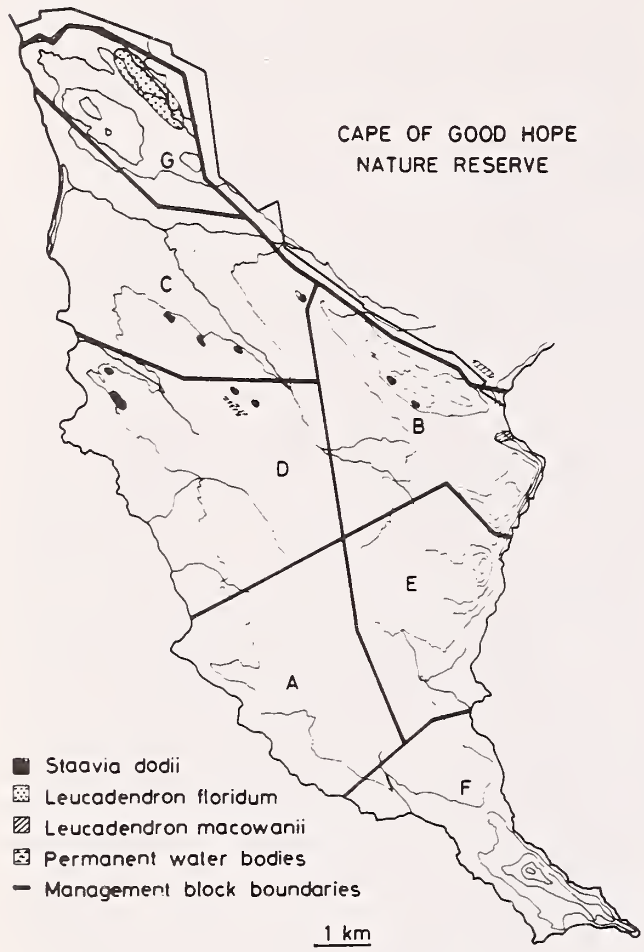

Figure 1--Cape of Good Hope Nature Reserve, showing contours at 61 m intervals; major streams; sites of the three rare species discussed in the text, and the proposed management blocks.

L. macowanii retains its seeds in a serotinous cone until the bush is destroyed; *L. floridum* sheds its seeds in April when the first winter rains are soon likely to fall (Williams 1972). Despite this difference, the seeds of both species retain their viability for at least two or three seasons, and the seed is not destroyed by burning. Indeed, both species regenerate freely after a fire but hardly at all without it. Young plants may take three years to form the first viable seed, but a period of at least five years between fires is needed to ensure a sufficient seed reserve for reasonable regeneration (I. Williams, pers. comm.). Thus in contrast with *S. dodii*, these *Leucadendron* species can regenerate independently of the burning season; only the burning interval is crucial. They are rare partly because they have been too frequently burnt, but mainly because their lowland habitats have been largely destroyed by man.

Even in the Reserve, habitats are still being diminished by woody weeds introduced by man from Australia and the Mediterranean during the last 150 years (Taylor 1969b, 1975, Hall and Boucher 1977). These invasive plants now present a far graver threat to our flora than the past evils of frequent burning and flower-picking combined. In the Cape of Good Hope Nature Reserve, *Acacia cyclops* A.Cunn. ex G. Don and *Pinus pinaster* Ait. are invading chiefly the rocky, sandy upland areas, *A. saligna* (Labill.) Wendl. and *A. longifolia* (Andr.) Willd. the moister areas with deeper soil. In time, these and other species form thickets that suppress and eventually replace the natural fynbos. Ten years ago, invasive plants were recorded at no less than 90% of sample sites distributed systematically throughout the Reserve (Taylor 1969a), and since then, despite efforts to control it, infestation has increased alarmingly both in density and frequency (Taylor and Fugler in preparation).

Unlike that of most fynbos, *Acacia* seed is exceptionally long-lived. Year by year, huge reserves of viable seed are built up in the soil; between 125 and 250 million seeds per hectare have been recorded in the top 10 cm of soil for *A. saligna* and *A. cyclops* respectively (S. Milton, pers. comm.). Thus frequent fires, instead of diminishing the invaders, greatly increase their spread, especially as *Acacia* germination and survival is extremely efficient and seedlings outgrow their indigenous competitors. Nevertheless, fire can be a means of controlling the Acacias if, after a burn, the seedlings are systematically pulled up or chemically treated.

With this aim, a management plan for the Reserve was drawn up in 1974. The total area was divided into seven blocks (fig. 1), five of which were to be burnt in the first ten-year cycle - one every two years - and the weed regeneration continuously removed. The two remaining blocks, already heavily invaded, would be included only in the second cycle either by enlarging the blocks or by lengthening the rotation. In this way the whole Reserve, excluding specially protected sites, would be burnt once every ten to fourteen years, which was considered long enough to ensure that all indigenous species were maintained while invasive species would be syste-

matically removed.

After the second block burn which took place this year, the plan has most unfortunately been discontinued. But fire remains the only practical management tool that, together with weed eradication, can serve to perpetuate our fynbos, control invading species and, in so doing, provide a permanently viable habitat for the animal component of the ecosystem. With intensified research, publicity and education one can only hope that this policy will become generally accepted before it is too late.

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THE ROLE OF THE TALL TIMBERS RESEARCH STATION IN THE DEVELOPMENT OF THE STUDY OF FIRE ECOLOGY[1]

E. V. Komarek[2]

Abstract: Partial history of the development of the study of fire ecology and the role played by Tall Timbers Research Station in research and education.

Key words: Fire, ecology, forest, grassland, prescribed burning.

Mr. Chairman and friends:

When Dr. Mooney asked me to give the banquet address with the title "The Role of Tall Timbers Research Station in the Development of the Study of Fire Ecology" I quickly accepted for there is nothing I would rather do than talk of Tall Timbers and its contributions to ecological understanding.

The title can be broken down into three separate parts. (1) The Role (2) Tall Timbers Research Station and (3) The Development of the study of fire ecology.

Now, the word role has different meanings but the most common definition, "a part of character performed by an actor in a drama," is the one I have chosen. Certainly the history and application of fire ecology with its many controversies and differences of opinion for at least over 2000 years can well be considered a drama.

Also, the word role has gradually been changed to r-o-l-l and some of these definitions are:

1. "To turn over in one's mind" "to ponder"

I have been turning over in my mind the ramifications of fire and its relationship to nature and man for nearly 50 years.

2. "To beat with rapid continuous strokes, as a drum"

As chairman of 15 consecutive Tall Timbers Fire Ecology Conferences and innumerable seminars and lectures over the world, there is no doubt that I have been beating the fire drums.

3. "To gad about, to wander, to roam"

Many will agree that this fits me quite well as I have studied the impact of fire ecology on six continents.

But I particularly enjoyed finding the illustration from the poet Dryden "And his red eyeballs roll with living fire." I will try to live up to Dryden with all the energy I can muster in the years ahead. I will try to channel this energy for a more widespread recognition of the need and acceptance of controlled fire in many ecosystems of the world.

SETTING THE STAGE

"For all the world is a stage . . ." and the stage for our drama on the Development of Fire Ecology is the earth.

Tall Timbers Research Station is but the culmination of events of the past, including such fundamental happenings as geology,

1/Banquet address presented at the Symposium on Environmental Consequences of Fire and Fuel Management in Mediterranean Ecosystems, Palo Alto, Calif. Aug. 1-5, 1977.

2/Executive Secretary, Tall Timbers Research Station, Tallahassee, Florida 32303

climate, etc., that set the stage by developing an ideal environment for experimental studies as well as the ancient controversy about the place of fire in nature. Virgil and Varro, Roman poets, argued about the merits of the use of burning crop residues in 20 B.C. Virgil insisted that it was a good practice and now 2000 years later his viewpoint has been scientifically verified. (Komarek 1973)

To seek truth and understanding in diverse opinion on fire as "master or servant," "evil or good," "enemy or friend," was in 1958, the underlying reason for the establishment of the Tall Timbers Research, Inc. foundation. The founders recognized that solutions to fire problems involved scientific, educational, sociological and psychological understanding if good judgment was to rule over emotional opinion. Fire management, the use of controlled or prescribed burning, is based on science but in its application it becomes an art.

Fire and Life

Fire is a physical-chemical process, not an element, and antedates the evolution of life by billions of years. It is a fundamental process of the universe.

Life, however, is a comparatively new process on this planet and may or may not be a process of the universe. Fire and life, are intermingled, for life on earth exists on a small band between two fires; the molten interior and the celestial fire of the sun. Without either of which life could not exist. In addition, the earth's surface has been subjected to fires by agents from without and within such as vulcanism, friction, spontaneous combustion, but, above all, by lightning, the electrical match.

• Unfortunately fire has no vocabulary and that process from a burning match to a conflagration is called FIRE.

Although we easily recognize fire, it becomes a Herculean task to define it, particularly in ordinary and non-technical language. All fire, from a spark to a rocket engine, from a match to a lightning bolt are chemical and physical processes and operate under chemical and physical laws.

Definition

Now, just what *is* known about fire, flame and combustion? Fire is the outward manifestation of combustion, largely one of rapid oxidation observed as flames. Unfortunately, many of the processes that occur are so complex that scientists cannot explain them and some investigators are beginning to suspect that fire may even be a fourth state of matter - plasma.

> "There is not a law under which any part of this universe is governed which does not come into play, and is touched upon in these phenomena." (Farraday 1847) "The quantitative description of flames is a very recent development, and combustion phenomena are still less well understood than many nuclear and photosynthetic processes, for example."
>
> "Even the simplest flame involves several simultaneous chemical reactions as well as aspects of aerodynamics, head conduction and molecular diffusion." (Fristom and Westenburg 1965) (underlining added)

Complexity

The processes that take place in a forest or grassland fire are infinite in their complexity for rapid oxidation operates on an infinite variety of organic materials with different characteristics, structure, composition and moisture. They are also influenced by radiation, convection, conduction, as well as differences in flammability, ignition temperatures and meteorological conditions.

Fire in nature, whether in shrub, forest, or grassland, is not just one individual fire, but is made up of innumerable, individual, different, tiny fires. Like living matter where the single celled creature may appear simple but is in fact complex, each individual fire, each organic particle, and I am even tempted to say each cell, is an entity within itself and burns at its own rate dependent upon its construction and organic matter as well as such outside influences as moisture, wind, humidity, etc. These individualistic fires ignite other organic particles and then die. Furthermore, they keep their individuality except where the flames begin to merge and mix above the actual organic material that is burning. In fact, in some fires this does not occur except well above the actual combustion processes and in these cases the mixture can then ignite or "flash-over" with high intensity. This cannot happen to any great degree unless there is enough fuel to raise the ignition temperatures of this

mixture of gases, air, particles, etc., to the required level.

The fact that fires are made up of a multitude of individual tiny flames makes any fire appear to be made up of "cells," and so the expression the "living fire" is an apt one, even though it is usually only recognized by religious or philosophical thinkers and poets and writers.

> "The transmission of fire is discontinuous, for each flame is a new flame, different from the one that lighted it." (Alain 1968)

Yet, we scarcely differentiate between a spark and a conflagration - from a pine torch to a blazing building. <u>Much of the turbulent history and controversy about fire in nature has been a lack of this understanding</u>.

PROLOGUE

Three, four, five or more million years ago, a creature appeared on earth that either evolved with or moved into a fire environment - our ancestor. He was a grassland, not a forest creature, as the abundant grassland animal bones mixed with his own fossil remains starkly testify. He hunted over and sought out recent burns caused by natural fires even as the baboons of Africa do today. Somewhere along the line an intelligent ancestor learned that he could grasp a burning branch and start his own fire. When this event occurred, fire became a very important, if not his most important possession, and someone had to be put in charge to keep it alight because it could only be rekindled from another natural fire. This may have been the beginning of what we call culture.

THE "CRADLE OF WESTERN CIVILIZATION"

As mankind developed and plants and animals were domesticated, early man progressed from hunter-gatherer, to shepherd or farmer.

The combination of domestic cereals, grasses such as barley, wheat, rye, oats, millet, along with grassland animal products produced sufficient food not only for himself and his family but for many others. First villages, then cities developed both symbiotic and parasitic upon the grazer and peasant cultivator.

Grasses and grass-like plants require considerable sunshine and herds in the open oak and pine Mediterranean parklands of the region and the farmland increased. As the cities grew, trade and other industrial types of development such as smelting, mining, etc., increased and a greater need for forest timbers developed. Up to this time the forests, particularly if they were dense, had little value to man and he destroyed them whenever he needed to make more grazing or farmland, with fire as his major tool. Let us not forget that he had to be an applied fire ecologist for he had to eat. The early people of that time, shepherds, and farmers, were certainly "fire-selected" as much as the grassland plants upon which they depended for food.

With the development of the Iron Age, need developed for charcoal in smelting and construction and the forests became denuded. With deforestation by timbering, came fire, and the shepherd expanded his range. The trees brought him no food but the timber income to the cities. And it appears to me that about this time arguments must have developed between those whc believed in burning and those who did not.

EXPLORATION BY SPANISH AND PORTUGESE IN THE AMERICAS

When the Spanish and Portugese conquistadores came to the New World they found vast grasslands in South and Central America, and the southern part of the United States, most of which were sparsely inhabitated by man and with few native grazing animals. The conquistadores differed from other explorers for they came primarily for the Cross and for gold. Above all, however, they merged some of their culture with that of the local peoples instead of destroying the natives.

Most of the conquistadores came from a small area in Spain, Estremadura, a region where sheep, cattle and goats were a major source of livelihood and most importantly they came from a region where fire had been used as a tool for grazing for a long time and still is. The Spaniards, accustomed to burning in their native lands, did little to hinder a similar custom of the Indians and probably assisted them as they had no bias against fire.

Along with the conquistadores came Franciscan friars. The southeastern Indians were agricultural people and when DeSoto came to Tallahassee (an Indian word meaning "old fields") he found fields six miles in extent in the region and it became a major food production area or "bread basket" for the Spanish empire in the New World. Here again, there was no apparent bias by the

Spanish against fire so the old Indian custom of burning prevailed, aided perhaps by the Spanish friars.

CENTRAL EUROPEAN COLONIZATION OF THE NEW WORLD

The major purpose of the explorers on the eastern seaboard of the United States, first Dutch, then British, French and German, etc., was for the development of additional colonies. The settlements were not the type where the newcomers merged with the native Indian peoples. They introduced into the region a typically central European culture accompanied by towns or villages, and a kind of farming that very closely resembled that of the homeland. They sought out the broad-leaved trees such as oaks, to clear-cut for their farming ventures. Livestock was not allowed to range as freely as permitted by the Spanish. Although the use of fire was common in the homeland for sheep grazing on heaths, most of the natural grasslands in Europe had been changed into highly cultivated meadows. In fact, these people had no true word for "grassland," "plains," or "prairie." Thus when Long Island, New York was first settled the rolling grasslands were called "desolated, moor-like Downs."

Furthermore, when the Dutch first settled New Amsterdam,their agreement with Indians on October 4, 1665, said:

> "Indians are not to set fire to the grass before the month of March without consent of the town." (Taylor 1923)

Forty-five years later the settlers had cut down most of the local forest. Wood was in short supply and we note the following:

> "It now becomes necessary to provide against the frequent fires which were found more destructive and in 1710 the trustees were authorized to call out the inhabitants to assist in extinguishing them." (Taylor 1923)

It must also be remembered that the villages were all made of wood. In designing wooden houses man had developed one of the most flammable types of fire systems - one that not only in this country but in many parts of Europe was the major cause of entire villages, and even cities being burned on a more or less regular basis. This constant burning down of cities in central Europe also developed an honest fear and bias of all fires.

Thus, the final interpretation of fires has had two somewhat different historical developments: one, based in central Europe on the destruction of forests by fire, many times after lumber operations when more fuel was allowed to accumulate than nature ever intended, as well as the destruction of villages and cities. The other, based on the need for burning for both the grazing of livestock and for farm purposes in the Mediterranean basin. The latter led to the long continuation of annual or nearly annual burning for livestock in the Tall Timbers region and the southern states long after it had been prohibited in the North.

THE TALLAHASSEE "RED HILL" REGION OF NORTH FLORIDA

Although Tall Timbers Research Station was established in 1958 in the "Red Hill" country of north Florida, its genesis occurred at a very early date. Institutions, if they are to evolve and understand the world around them, must have a congenial climate, a satisfactory environment, and a proper habitat to succeed. So our beginning at Tall Timbers takes place properly a long time ago - some 65 million years ago when the North American continent had a tropical climate and environment. It was then split in two; into eastern and western sections by a "seaway extending more than 6,000 kilometers in a north-south direction and 1500 kilometers from the Rocky Mountains almost to the Mississippi River" and the waters of the Gulf of Mexico were mixed with those of the Arctic Ocean.

At the beginning of the Tertiary period most of this seaway became dry land again and was one of the world's largest grasslands, extending from Canada to northern Mexico, and extended eastward along the coastal plain of the Gulf of Mexico and the Atlantic Ocean as far north as New York State. This grassland has remained in the Southeast to the present day under the filtering light of Southeastern pines except where disturbed by the activities of man.

Much later, glacial ice covered most of the northern part of the North American continent except for some pathways. This forced both flora and fauna southward into the Southeast as well as into the Southwest and Mexico. Thus, the Southeast became a refugium for many plants and animals including the prairie plants and earthworms.

Deep in the Coastal Plain of southeastern United States, among the Tallahassee Red Hills, about 100 meters or so in height and within 60 kilometers of the Gulf of Mexico, lies Tall Timbers Research Station.

In these pine savannas there are three major sources of fuel. One is the grassland that underlies either the pine or the open hardwood forest. The second is the pine needles themselves. A third, although only in certain areas and only prevalent in the absence of fire, are certain brush species that are highly flammable. In addition, it is a region of considerable lightning. Therefore, with good soils, and subtropical climate, a plant succession that is extremely rapid occurs so that experiments can be established and results seen in a very short time. Where fire is prohibited this grassland or savanna is turned into a bushland or a young treeland shortly - within four years.

This, then, is the habitat of Tall Timbers.

COOPERATIVE QUAIL STUDY INVESTIGATION

Timber in Tall Timbers region was clear-cut and the land was intensively farmed before the Civil War. The War destroyed a centralized agriculture and replaced it with scattered patches of farm land of about 100 hectares each intermingled with land that was allowed to revert back to forest lands which were burned annually for grazing of livestock and other purposes. This pattern of annually burned open pine woods interspersed with small fields of corn and other crops became famous as quail hunting country. As long as the share cropper system remained with its highly diversified pattern of agriculture, small tract lumbering and annually burned open land, the region maintained a satisfactory quail population.

However, in 1920 a new factor entered into the picture. Florida, along with other southeastern States and the federal government, was quite concerned with the extensive cutting of America's forests and an intensive campaign was started to re-establish timber back on the land. A great evil was then said to be fire. By 1923 that program was so successful in the Thomasville-Tallahassee region that the formerly open pinelands became brush-choked and the quail population drastically decreased. This alarmed the plantation people, so a meeting was held and it was agreed to finance a scientific investigation to determine why quail populations had decreased. (Komarek 1977). That meeting led to establishment of the Cooperative Quail Study Investigation, 1924-1928, headed by Herbert L. Stoddard.

Stoddard, who had spent part of his boyhood in central Florida, not too far from Orlando, grew up where annual burning of the pine woodlands was the custom for cattle grazing and he also learned to trap quail for food. Thus, at a very early age in his life he came to understand fire much as shepherds and farmers do in other parts of the world. Within his first year in the Thomasville-Tallahassee region he sent a report (1925) to the members, that he thought that lack of fire might be the key to the shortage of Bobwhite. Stoddard finished his investigation four years later which confirmed his original observation. The quail population came back rather miraculously and Stoddard became known as "The Wizard." With the publication of his famous book <u>The Bobwhite Quail, Its Habits, Preservation and Increase</u>, 1931, game management or wildlife management as we now know it, really began. He was the first individual to demonstrate scientifically that the wildlife on a tract of land was actually a crop of the land whose population could be manipulated by the practices on that land. He also pointed out in his book:

> "<u>Fire may well be the most important single factor in determining what animal and vegetable life will thrive in many areas</u>." (Stoddard 1941) (Underlining added)

COOPERATIVE QUAIL STUDY ASSOCIATION

After the conclusion of the Cooperative Quail Study Investigation, Henry L. Beadel, owner of Tall Timbers Plantation and donor to that investigation, suggested the organization of the Cooperative Quail Study Association, 1932, which became a consulting research service in game management to plantation owners as well as to public agencies. Henry L. Beadel was Secretary, Stoddard was Director, and I came into the organization as Stoddard's assistant on July 1, 1934.

From 1931 to 1943, the Association worked on or was consulted on, over 100 plantations of about 10,000 acres each, scattered from North Carolina to Arkansas, as well as with several government agencies. Throughout the Association fire and its uses in wildlife, forestry and agriculture were of primary importance. Stoddard and I were known as "quail doctors" and one does not usually call in a doctor unless one is sick. And so it was with hunting plantations. In well over 75% of the plantations we worked with,

fire exclusion was the principle factor for declining quail abundance. The other 25% or so was because of improper forestry operations or improper distribution of agriculture.

On April 15, 1943 the Association was disbanded. One reason for its demise was the fact that certain forestry and agricultural practices were developing at a rapid rate which were detrimental not only to quail but to much other desirable southeastern wildlife. It was felt that more impact could be brought to bear on these practices if Stoddard and I became active privately in forestry and farm management. Thus, H. L. Stoddard became a registered forester and wildlife consultant, in which capacity he remained until he died. I became deeply involved in agriculture and wildlife also as a private consultant.

At the end of the quail investigation Stoddard was given a 1,000 acre property which is now known as Sherwood Plantation. In 1938 we (the Komareks) acquired 565 acres, Birdsong, adjoining Sherwood on the south. Both properties are not far from Tall Timbers Plantation. Thus, for many years Stoddard and the Komareks were able to do considerable burning annually on their properties at various times of the year, experimentally as well as for management purposes. However, a much larger area was really needed to test out ideas and theories that had developed over the years.

THE GREENWOOD PROJECT

In 1945 we were given that opportunity when my brother Roy and I were asked to take over the management of Greenwood Plantation (John Hay Whitney, owner), with instructions to "do something with the property to benefit southern agriculture," to develop Greenwood's forests along the lines originally discussed by Stoddard and to develop game and other resources along lines mentioned in our Cooperative Quail Study Association reports.

Stoddard was retained as consultant in forestry and game. In the development of the agricultural potential, Greenwood teamed up with the U. S. Department of Agriculture, the Georgia Coastal Plains Experiment Station, and the Florida Experiment Station. This cooperative action resulted in the development of the first really successful southern hybrid corn (maize) and the beginning of the southern corn belt as such. All of this agricultural development was blended into a modern program of quail management.

Thus, on 18,000 acres we had an opportunity to test ideas in connection with fire ecology that we had been thinking about a long time, not only for quail and wildlife management but for forestry and agricultural purposes as well.

A DREAM BECOMES A REALITY - TALL TIMBERS RESEARCH, INC.

For over 25 years a Sunday morning informal meeting had developed in front of my wife Betty's bird watching window at Birdsong. At these meetings the idea of a wildlife experiment station was discussed among those scientists and interested laymen who came that way for the coffee hour. Henry L. Beadel was a frequent member of this "coffee klatch." Stoddard had pointed out in his "Bobwhite Quail" that fire and the effects of burning -

> ". . . present a complex problem, one that would require years of careful research on the part of the personnel of a well equipped experiment station to work. Such research is greatly needed and should be carried on, for fire may well be the most important single factor in determining what animal and vegetable life will thrive in many years." (Stoddard 1931)

We had long since realized that individually we were not progressing very rapidly in trying to change opinions of foresters and bureaucratic policies in relation to the use of fire in land management. If we had been forced to stop all burning, and I was threatened by arrest for burning a client's land in 1938, not only would the quail, a grassland bird, but other desirable wildlife would have virtually disappeared. (Komarek 1973; also see Biswell 1977, this symposium)

On the organizational night of March 15, 1958, what had begun as a vision became a reality. Vital and central to that reality was the establishment of an ecological experimental station. The purpose of the foundation was -

> "a quest for ecological understanding"

not only in fire ecology, but -

> "its aim has been to combine the study of natural history and ecology (which was once known as 'scientific natural history') with science education and healthy doses of 'historical ecology'." (Komarek 1977)

The founders recognized the absolute necessity of developing public and scientific interest through long-term experiments, research, and demonstrations. This meant a research institution so well structured and of such permanence and continuity that experiments lasting a century or more could be undertaken and brought to fruition, and where no subject of investigation was taboo in and of itself. There is real danger that the work of closely controlled governmental (or even commercial) research institutions will tend to reflect policy at best - and politics at worst - instead of objective study.

The history of fire ecology and its relationships to the ecology of plants and animals as well as man shows the danger of such a situation. For example, a governmental agency so dominated the research field of fire ecology in both government and academic worlds that there was an overwhelming need for a book to be written entitled "Fire and Water: Scientific Heresy in the Forest Service" (Schiff 1962) in which the dangers and effects of such dominance were clearly pointed out. (see also Komarek 1973) The present pesticide controversies also serve to point up the lack of independent, privately organized, yet public, non-governmental biological research organizations.

THE ROLE

The greatest role, in my opinion, that Tall Timbers has played in the development of fire ecology has been educational, due to our Fire Ecology Conferences and Proceedings, along with the constant stream of visitors to the Station, and with the fire research accumulated by its four predecessor organizations beginning in 1924, all of which had been privately financed. (Komarek 1977)

My associates and I had long ago realized that the studies, discussions, and controversies in fire as a whole appeared to be running on separate parallel tracks without any switches to merge their viewpoints. There appeared to be no communications either in the practice of fire management or in scientific fire studies. Also the individual investigators who realized that fire was an ecological factor were scattered all over the world. They were individuals lost in the annual meetings of scientific societies such as Forestry, Ecology, Range Management, and conservation agencies as well. University research scarcely recognized there was any ecological value in fire or that there was a fire ecology in 1958.

We recognized that if we were to meet our Charter's goals in relation to fire ecology

> "to instruct the public on subjects useful to the individual and beneficial to the community"

we would have to search the world for these isolated individuals interested in fire ecology, bring them together informally if possible, and then publish results of their studies, for our Charter also charges us:

> "to publish and distribute to the public generally any knowledge or information acquired of such research, experiments, and studies. . ."

We had also recognized that a large part of the difficulty about fire was due in great measure to the fact that the process of thought by mankind on any subject whether it be fire, religion, science, philosophy, or on social or psychological problems, is extremely varied. However, the processes of thinking can be characterized by two basic viewpoints, deductive and inductive reasoning. If we were to succeed we had to bring these two approaches together.

DEDUCTIVE AND INDUCTIVE REASONING

Mankind's thinking processes are very complex and diverse but two kinds of reasoning are most evident, not only in ordinary life but among scientists, even ecologists.

1. Inductive reasoning. This can be explained largely as working from a particular case to a general principle. As an example, the devastation of a forest by fire connotes that all fire is destructive; a principal idea that came out of central Europe.

2. Deductive reasoning. This is the drawing of a specific conclusion from general principles. This is the reasoning most shepherds, farmers and those close to the land largely use. Both the shepherd and the peasant, non-mechanized farmer, spend many hours on the land with their animals and crops so they have unlimited opportunities to observe, to ponder, and to revolve in their minds upon influence of fire on forage and animals.

Throughout the history of fire ecology these two types of reasoning have clashed and much of our controversy in the past and lack of development in fire ecology can be traced to these differences of opinion. Each side of the contest draws upon, enlarges, and in many cases disregards the truth in each other's field, to win his argument. However, the

foresters and associated conservation people were from the very start more organized, better missionaries, if you will, and because the use of forests was primarily for commercial development, funds were more readily available. It is difficult to organize farmers or shepherds anywhere in the world. Much of the difficulty was that -

> "Woodland and grassland stand opposed to one another like two equally powerful but hostile nations, which in the course of time have repeatedly fought against one another for the dominion over the soil." (Schimper 1903)

and that the connotation by central European foresters as to the importance of forests had pervaded the public mind so that they had forgotten the sustenance of the world is in its grass cover and the animals that eat it, not in its forests.

> "to consider grassland, as is frequently done, as the sign of a 'bad climate,' as an evidence of poverty in Nature, as a transition between forest and desert, is at best comprehensible from a forester's point of view, but is neither scientifically nor practically justifiable." (Schimper 1903)

In 1926, E. A. Greswell, Forester of the Indian Forest Service in India wrote:

> " . . . statements. . . by writers. . . have forced me to the conclusion that our management has hitherto been based on pussyfoot principles. Excessive indulgence in alcohol is no argument for total prohibition. The same applies to fire and grazing and perhaps other natural phenomena to which our forests have been subjected for centuries. We talk glibly about following nature and forget that the nature we are visualizing may be an European nature inherited from our training. . . We, therefore, intuitively welcome the proof provided by the few cases in which they are so and by inductive reasoning arrive at general conclusions which may be incorrect if not dangerous."

As recently as 1959, the late John T. Curtis, Plant Ecology Laboratory of the University of Wisconsin, wrote that the prairies and savannas of that state -

> ". . . have become victims of the bureaucratic dictum, that since most forest fires are the source of economic loss, therefore all fires are bad and must be prevented at any cost. This dogma has been supported by such an intensive propaganda campaign that there is danger of its being accepted as truth."

Likewise, this philosophy had, because of this European tradition on the importance of forest growth, impregnated much of the plant ecological and phytogeographic classifications so that these, with few exceptions, had little regard for fire as an ecological factor. Throughout much of this classification of plant communities fire has been considered purely a human artifact. Even Braun-Blanquet (1932) considered:

> "Fire. - The most remorseless associate of man in the destruction of native vegetation is fire."

I am reminded of a statement by Bews (1931) in "The Ecological Viewpoint:"

> "The whole trend of modern science is inevitably towards a more and and more detailed analysis of natural phenomena. The fascination of taking things to pieces makes a very strong appeal to us from childhood onwards. Mere analysis, however, is comparatively easy, and, on the whole, not of the highest importance, unless it leads on, as it should to further synthesis. Moreover, the synthetic process should not be confined to concrete forms or structures. Science if it is to show real progress, must deal with <u>general principles or tendencies, or in other words, it must invade the realms of philosophy</u>. (Bews 1931 - underlining added)

Although this was written 46 years ago it is essentially true today and in some circles is accentuated by the use of calculators, computers and mathematical designs as if we were dealing with non-living materials.

In a recent issue (March 1977) in the <u>Bulletin of the Ecological Society of America</u>, is the following comment:

> ". . . And I recall a remark made, too many years ago when we were made grad students, by a recent president

of ESA to the effect that perhaps we would learn as much or more if we sat on a stump and just contemplated our surroundings instead of madly measuring and recording data."

"My point is that ecology is as much a way of looking at things as it is a body of scientific data, that in effect it is in part an art and therefore intuitive." (Whitford 1977) (underlining added)

This then, was the background when we organized in 1958. We had assembled and accumulated much information on fire ecology and controlled burning from the previous four organizations. This had been gathered by both deductive as well as inductive reasoning. During those 34 years we had seen the need for long term experiments.

FIRE RESEARCH

As soon as the Station was organized, plans were made for -

"Long-term or "Classical" Experiments or Studies. It was recognized before the inception of the foundation that experiments or studies extending over a long period of time were vital to the understanding of the ecology of north Florida, south Georgia and south Alabama (the Tall Timbers "region"). It was felt that the effect of disturbance by man or nature (including fire) could not be perceived except over many years." (Komarek 1977)

The Stoddard Fire Ecology Plots consisting -

"of squared 84 half-acre plots laid out in 1959 by Herbert L. Stoddard, on what are now the station grounds. These were set up to study the effects of controlled burning over varying intervals, ranging from annual burning to burning every 75 years. Plots to show total fire exclusion were also included." (Komarek 1977)

A large additional plot was established, the Fire Ecology Study NB66 . This was set up:

"To determine what actually happens during plant succession on upland sites, a 22-acre area was set aside on Tall Timbers Research Station in 1966 with the avowed purpose of protecting it from fire for over 100 years. This area was marked off into 48 conerminous plots measuring 30 by 60 meters." (Komarek 1977)

In addition, ongoing experiments are being conducted on the fire relationships of several species of birds, mammals, reptiles, amphibians and invertebrates such as beetles, ants, snails, and earthworms, as well as various species of plants. An in depth study on the fire relationships of the fungi of the region is in its fourth year. In addition to our staff studies, these and other regularly burned or unburned areas are being utilized more and more intensively by investigators from other institutions and agencies.

FIRE ECOLOGY CONFERENCES

We started out these conferences with individuals concerned with fire problems here in the Southeast and for the first time the term "fire ecology" was used. I note that at that first conference we had botanists, foresters from both Federal and State forest services, including the Assistant Regional Director of the U. S. Forest Service, wildlife biologists, forest researchers, wildlife managers, an anthropologist, and even a retired architect. The attendance included representatives of many agencies as well as private individuals.

The conference exceeded our expectations and the demand for the Proceedings grew to such an extent that soon they were being published in editions of over 5,000 copies. The 14th Proceedings was published in 6,500 copies. Today all but the later Proceedings are out of print.

At the 15 conferences over 400 authors have given 285 titles totaling 4,918 pages. Our Proceedings started out with only 186 pages and 15 speakers. The joint conference with the Intermountain Fire Research Council at Missoula, Montana went to 675 pages with 42 speakers. Most of the conferences have been held at Tallahassee but whenever we felt it necessary to stimulate fire ecology, we held them elsewhere. The first meeting away from home was held at Hoberg, California. The next was held in New Brunswick, Canada; the third at Lubbock, Texas; the fourth at Missoula, Montana, and the fifth in Portland, Oregon.

We focused on certain regions, for the old refrain in the early years was - "it works here in the South but it won't do so in other regions." Some of these regions have already been mentioned above but in addition we

focused one meeting on Africa and another on Europe.

The 15th conference was the last regular conference, for by this time we had felt we had accomplished our objective which was to stimulate fire ecology and fire management. There is so much investigation in fire being conducted in the United States today by various governmental agencies as well as universities and conservation groups that we can no longer keep up to date with the many studies going on. In addition, there have been a large number of symposia, workshops, and meetings. In the past 12 months there have been important fire ecology and fire management meetings in Atlanta, Georgia; Anchorage, Alaska; Freiberg, Germany, and St. Maximin, France.

TASK FORCE

In addition to the conference Proceedings, a "Task Force" was established to look into the fire problems of the ponderosa pine in the Southwest. This task force consisted of Dr. Harold Biswell, Harold Weaver, Dr. Richard Vogl, Harry Kallander, and Roy Komarek. Their report was our Miscellaneous Publication No. 2, which has been in great demand and has had to be reprinted twice, because of demand by forest and park agencies.

THE CONTINUING ROLE OF TALL TIMBERS

It is with considerable surprise that we find only a small amount of prescribed or controlled burning being conducted in California and other western National Forests, National Parks, and other wildland managing agencies. This is particularly in contrast to the southern region where the U. S. Forest Service had a week long workshop largely for its own southern personnel. It was pointed out that at that time 2 1/2 million acres are being prescribed burned annually and that the goal in the southern region should be 10,000,000 acres annually.

The Missoula - Tall Timbers Fire Ecology Conference was held jointly with the Fire and Land Management Symposium of the Intermountain Research Council and was published by Tall Timbers as its 14th Proceeding. In that proceeding is the following statement from Henry W. DeBruin in his paper on "From Fire Control to Fire Management, A Major Policy Change in the Forest Service."

> "Fire management is change: It is in concept, a change in policy, and a change in action. The Forest Service is changing. . . We are changing from FIRE CONTROL, a simplistic approach easily communicated and understood, to FIRE MANAGEMENT. . . a complex scientific approach, not so easily communicated or understood."

Apparently, this policy has not filtered through to the supervisors and their assistants in the western states, particularly California. Perhaps it is also not understood.

During the past two weeks while this symposium was being conducted, we have witnessed a steady stream of uncontrolled wildfires in California ignited by lightning, <u>but caused by allowing such heavy fuel loads to accumulate</u>. When asked why such fires are not controlled, forest service personnel made the following remarks to a news reporter in describing the intensity of the fire:

> "One acre of that fuel - brush and oak trees - is like 6,000 gallons of gasoline." (Alexander 1977)

> "To put it more strongly, 1,000 acres is equivalent to the bomb they dropped on Hiroshima. That's a lot of power, when you're talking about 50,000 acres." (Alexander 1977)

Thus, the natural question is to ask WHY. Why has such hazardous flammable fuel been allowed to develop when the scientific expertise as well as the art of prescribed burning is available in California today. Forest, watersheds, wildlife values, etc. are being destroyed not by fire but by the lack of what Mr. DeBruin has called "Fire Management."

Chief John R. McGuire in his paper at the Missoula conference titled his paper "Fire as a Force in Land Use Planning" and said:

> ". . . Fire is one component of total forest ecology. . .
>
> . . . Fire management cannot be separated from total forest management . . . We must now anticipate change, and plan for change . . .

These concepts of policy change and fire management which include the use of prescribed fire apparently have not reached California. Because of this the TASK FORCE, with Dr. Biswell as chairman, that did such a splendid job in 1972 has been reinstated and will up-date the publication on Ponderosa Pine Management, and seek to learn why prescribed burning is not now being practiced in California, as a protection against

wildfire. Their scope will be enlarged to include such areas as those dominated by mixed forest of Ponderosa Pine, Sugar Pine and its associates as well as the progress in the protection of the Sequoia. The Task Force will have an additional sub-section on the management and the use of prescribed burning in chapparal.

And, finally, because of the inability of the forest fire control forces to control wildfire in wildlands largely due to the fact that fire prevention, the use of prescribed fire, has not been used (except in some areas to remove the residue from lumber operations and very meagerly to remove hazardous fuel accumulations) we must take further action. For 43 years, 20 years of which I have been Executive Secretary of Tall Timbers Research Station, I have learned to my sorrow that neither science nor education can resolve the fire problem in California, Arizona and other western states. The only other course is political action and alerting conservation and environmental agencies to this problem.

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* U.S. GOVERNMENT PRINTING OFFICE : 1977 0-241-426/9

Mooney, Harold A., and C. Eugene Conrad, Technical Coordinators
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